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Metasomatic uranium mineralisation of the Mount Isa North Block

A. Otto, J. Jory, J. Thom, E. Becker
Paladin Energy Ltd, Perth, Australia

E-mail address of main author: alexander.otto@paladinenergy.com.au

Abstract. Proterozoic uranium deposits of the Mt Isa North Block are centred 40 km north of Mt Isa, NW Queensland. Regionally, the deposits occur within the Leichhardt River Fault Trough of the Mt Isa Inlier. Uranium mineralisation is likely related to the 1 600-1 500 Ma Isan Orogeny. Structurally-controlled uranium mineralisation is preferentially hosted in greenschist facies basalts and interbedded clastic sediments of the Eastern Creek Volcanics (ECV). Uranium deposits of the Mt Isa North Block are defined by the following general characteristics:

- Pervasive sodium and calcium metasomatism, expressed as red albitite with finely disseminated hematite and calcite, with distal zones of chlorite and magnetite.
- Uraniferous albitite deposits typically comprise en echelon lenses and shoots.
- Mineralisation is developed along N- to NE-striking shear zones with associated brittle deformation of the host lithologies.
- Host rocks are mostly basalt flows with flow-top breccias and interbedded sandstones and siltstones of the ECV; quartzites are also locally mineralised.
- Uranium mineralogy of albitites comprises brannerite, coffinite, uraninite and uraniferous zircon.

The Mt Isa North Blocks includes 11 tenements being explored for uranium by Summit Resources. Summit’s five uranium resources total 95.7 Mlb U₃O₈. Summit is in a 50/50 Joint Venture with Paladin on the Valhalla and Skal deposits. Paladin also has a direct ownership of 81.99% of the issued shares of Summit Resources.

1. Introduction

The uranium deposits of the Mount Isa North Block are located north of Mount Isa, Northwest Queensland, Australia (Fig. 1). Historically, uranium mineralisation in the Mount Isa region was considered similar to the Olympic Dam IOCG-type Cu-U-Au deposits and the nearby Ernest Henry Cu–Au deposit. Recent petrographic studies by Paladin have demonstrated that much of the ‘red rock’ alteration in the Mount Isa uranium deposits is due to albite and finely disseminated hematite caused by sodium and calcium metasomatism. These uranium metasomatite deposits are analogous to similar deposits which have been mined in Russia, Ukraine, China and Canada (e.g. Beaverlodge and Gunnar). The Valhalla and Skal uranium deposits were discovered by prospectors in 1954 and since then has been explored by MIM, Queensland Mines Ltd and Summit Resources.
2. Regional geology

Two major Proterozoic tectonostratigraphic cycles are recognised in the Mount Isa Inlier [1]. An earlier cycle is represented by basement rocks metamorphosed and deformed during the Barramundi orogeny (1 900-1 870 Ma) (Fig. 2). A later cycle, represented by cover sequences 1-3, was terminated by the Isan Orogeny at 1 620-1 520 Ma [2]. Cover sequence 1 is mainly felsic volcanics, cover sequence 2 includes shallow-water sediments and bimodal volcanics, and cover sequence 3 is mostly fine-grained clastic sediments and carbonates. Large granitic batholiths were emplaced at ~1 860 Ma, 1 800 Ma, 1 740 Ma, 1 670 Ma and 1 500 Ma. Abundant mafic dykes of mostly gabbro and dolerite compositions range from 1 900-1 100 Ma. Extensional deformation during the second cycle was terminated by the compressional Isan orogeny, which consisted of two main phases: 1) early thrusting and folding during north-south compression with localized basin inversion, and 2) upright folding, reverse faulting and dextral wrenching during east-west compression. Subsequent strike-slip faulting divided the area into several tectonostratigraphic belts.
The Mount Isa Inlier is subdivided by north-south-striking faults into three tectonic belts: Western Succession, Kalkadoon-Leichhardt Belt and Eastern Succession [3]. The Western Succession includes the Lawn Hill platform (carbonate rocks), Leichhardt River Fault Trough (mafic volcanic rocks and clastic sediments), and the Myally Shelf (clastic sediments and carbonate rocks).

The Leichhardt River Fault Trough is dominated by mafic volcanic rocks of the Haslingden Group that were deposited in an intercontinental rift setting. The Haslingden Group consists of sandstone and quartzite of the Mount Guide Quartzite unconformably overlain by basalts and interbedded clastic sediments of the Eastern Creek Volcanics [1] dated at 1807 to 1710 Ma. A 6km-thick volcanic sequence was regionally metamorphosed to greenschist facies (calcite, chlorite, epidote). These rocks are strongly folded, faulted and foliated, and bedding dips steeply west and north. A total of 107 uranium occurrences have been have been recorded, including the Valhalla, Bikini and Skal deposits. Most of these occur in the Eastern Creek Volcanics.

FIG. 2. Regional geology of the Mount Isa North Block [4].
The Haslingden Group rocks were intruded by the Sybella Granite at 1670 Ma, resulting in extensive contact metamorphism of the Eastern Creek Volcanics. The Mount Isa Group unconformably overlies the Haslingden Group, and consists of carbonaceous and dolomitic siltstones, mudstones and shales. The 1655 Ma Urquhart Shale of the upper Mount Isa Group hosts the world-class Mount Isa Cu and Pb-Zn-Ag deposits. The Mount Isa region was deformed during the Isan Orogeny from 1620 to 1520 Ma, with at least three major deformation events. The D2 event was the most widespread with E-W compression producing N-S-striking upright folds and N-S cleavage. D3 deformation produced NW folds and ductile shears, and reactivation and dilation of older structures.

The Eastern Creek Volcanics are exposed over an area of 150 km N-S by 40 km E-W, with a maximum thickness of 7 km. The sequence is divided into three members: Lower Cromwell Basalt, Lena Quartzite and Upper Pickwick Basalt. Basalt flows have a massive, fine- to medium-grained texture that fines upward into amygdaloidal zones and are locally capped by 2-4 m thick flow-top breccias. Cenozoic alluvial deposits cover 40-60% of the region. The Valhalla deposit is covered by 2-30 meters of laterite and saprolite, whereas Bikini, Skal and Andersons crop out as low ridges and hills.

3. Valhalla

Valhalla is classified as sodic and calcic metasomatised, albitite-hosted uranium deposit. Uranium mineralisation is hosted by a 30 to 80 m thick package of albitised basalts and interbedded sediments. Bedding dips to the SW at moderate to steep angles. Regional greenschist facies metamorphism is indicated by the presence of epidote, chlorite and calcite. Sodium and calcium metasomatism are respectively expressed as albite, riebeckite, dolomite and calcite.

![FIG. 3. The picture on the left shows magnetic and radiometrics. The right picture shows the interpreted geology.](image-url)
The albite is typically accompanied by finely disseminated hematite, producing a characteristic red to pinkish red colour in mineralised zones. Mineralisation occurs along a NNW-striking shear zone. Importantly, the mineralised shear is about 20° oblique to the strike of bedding and is revealed in magnetic maps (Fig. 3). The main mineralised zone is up to 90 m wide, 1 km long and 650 m deep. The deposit geometry is cigar-shaped, which plunges at moderate angles to the SSE. There is a smaller mineralised zone, known as Valhalla South, located 700m SSE of the main body, with dimensions of 400 m long, 30 m thick and 150 m deep.

The albitites are characterised by the assemblage albite – carbonate – hematite. This alteration is marked by grain size reduction and the replacement of quartz, Fe-Mg-silicates and magnetite. The main uranium mineralisation coincides with the brecciation of the albitites (Fig. 4). The clasts are frequently deformed resulting in a rod like shape. The matrix is commonly fine grained but can contain small veins and mineralised voids. The colour is usually dark red relating to hematite but can also be dark green due to epidote and aegirine content. The composition of the matrix is highly variable. It consists mainly of albite, epidote, aegirine, zircon, hematite, carbonate, magnetite and various opaques. The matrix can contain more than 1 wt% uranium and 9 wt% zirconium. The uranium mineralogy is dominated by coffinite, uraninite, brannerite and uraniferous zircon. It appears that zircon is the earliest phase (Fig. 4.).

FIG. 4. The left picture shows a typical ore breccia. The bright clasts are dominated by albite, the dark matrix is highly mineralised. The right picture shows a back scattered electron image of zircon that is partially replaced by coffinite.

4. Skal

The Skal deposits are located 8 km southeast of Valhalla (Fig. 1). The Skal complex consists of four separate uranium deposits in an area of about 1 km². The uranium mineralisation is associated with intensive albitised quartz-veins, basalts and sediments, which occur in the centre of up to 400 m long and 30 m wide shear zones. The angle between these shear zones and the bedding is up to 45° (Fig. 5). The plunge of the ore shoots are at moderate to steep angles. The quartz veins were formed prior to mineralisation, which were subject to intensive brecciation during metasomatism and mineralisation. The albitisation is characterised by the assemblage albite – carbonate – hematite. This alteration is marked by grain size reduction and the replacement of quartz, Fe-Mg-silicates and magnetite. The uranium mineralisation coincides with the brecciation of the quartz vein (Fig. 6). The matrix represents the pathways for the sodic and uranium rich fluid. The most intensively altered and mineralized zones are at lithological contacts.

The uranium mineralisation is generally very fine-grained and comprises brannerite, uraninite and coffinite. The uranium mineralisation is associated with iron oxide alteration consisting of magnetite, hematite, albite, biotite and stilpnomelane. Traces of pyrite are concentrated in the areas containing uranium mineralisation.
FIG. 5. Simplified geology of the Skal deposit.
5. Anderson’s

Numerous north striking, mineralised shears cross cutting the stratigraphy (Fig. 7). The main uranium mineralisation is hosted by metasediments that dip at steep angles to the north. The ore body has a cigar-shaped geometry, which plunges with a steep angle to the east. It is parallel to the intersection lineation of the stratigraphy and the north striking shears. Uranium mineralisation is associated with sodic, calcic and phosphoric metasomatism.

FIG. 6. Typical ore breccia from Skal.

FIG. 7. Simplified geology of the Anderson’s lode deposit.
6. Conclusions

The main host of uranium mineralisation in the Mount Isa North Block are the Eastern Creek Volcanics. Important factors for mineralisation are the high competency contrast between lithologies and the intersection angle between startigraphy and mineralising structures. Anderson’s lode has the highest grades but forms a steeply plunging and short strike length ore body due to the high intersection angle and thin north striking structures. Whereas Valhalla has a small intersection angle and a large northerly striking structure, which resulted in a moderately plunging and much larger ore body (Table 1.).

Table 1. Resources of the Mount Isa North Block

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Measured and Indicated Resources</th>
<th>Inferred Resources</th>
<th>Paladin Share</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cut-off ppm U$_3$O$_8$</td>
<td>Mt</td>
<td>Grade ppm</td>
</tr>
<tr>
<td>Valhalla</td>
<td>230</td>
<td>27.80</td>
<td>891</td>
</tr>
<tr>
<td>Skal</td>
<td>250</td>
<td>11.5</td>
<td>483</td>
</tr>
<tr>
<td>Bikini</td>
<td>250</td>
<td>10.1</td>
<td>517</td>
</tr>
<tr>
<td>Andersons</td>
<td>230</td>
<td>2.0</td>
<td>1,050</td>
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<tr>
<td>Watta</td>
<td>230</td>
<td>4.2</td>
<td>410</td>
</tr>
<tr>
<td>Duke Batman</td>
<td>250</td>
<td>0.5</td>
<td>780</td>
</tr>
<tr>
<td>Honey Pot</td>
<td>250</td>
<td>2.6</td>
<td>700</td>
</tr>
<tr>
<td>Total</td>
<td>28.30</td>
<td>889</td>
<td>25,153</td>
</tr>
<tr>
<td>Total Resource Attributable to Paladin</td>
<td>25.80</td>
<td>889</td>
<td>22,924</td>
</tr>
</tbody>
</table>

REFERENCES

The main geological types of uranium deposits in Argentina

L. López

National Atomic Energy Commission (CNEA), Buenos Aires, Argentina

E-mail address of main author: lopez@cnea.gov.ar

Abstract. Several geological types of uranium deposits have been discovered in Argentina. The current uranium identified resources are 16,060 t U and belong to volcanic and caldera-related and sandstone-hosted models.

1. Introduction

The uranium-related activities in Argentina begun in the 1950s and, as a result of the systematic exploration, several types of deposits have been discovered since then: volcanic and caldera-related, sandstone-hosted, vein spatially related to granite (intragranitic and perigranitic) and surficial [1].

This paper briefly describes some examples and their contribution to the uranium resources of the country [2][3][4] (Fig. 1).

2. Geological types and resources

The deposits that have been exploitated in the past belong to the volcaniclastic type localized in Permian formations associated with synsedimentary acid volcanism in the Sierra Pintada district (Mendoza province) [5][6]. From this deposit 1 800 t U were mined, and the current identified resources are 10 010 t U recoverable at a production cost below US$130/Kg U [7].

Laguna Colorada deposit in the Chubut province [8] located in the San Jorge basin (Cretaceous) is volcanic and caldera related type, with evaluated resources of 100 t U [7].

Several important uranium occurrences have been identified in Cretaceous fluvial sandstones and conglomerates, among which the most significant is the Cerro Solo deposit (Chubut province) [9][10][11]. In this paleochannel structure, the mineralised lodes are 0.5 - 6 meters wide and 50 – 130 meters deep. The identified resources are 5 950 t U at 0.4 % U, included in the < US$130/Kg U cost category[7].

Other subtypes of sandstone model have been studied. For instance, the Don Otto deposit (Salta province), located in the Salta Group Basin (Cretaceous - Tertiary), belongs to the tabular U-V subtype[12][13]. This deposit was mined from 1963 to 1980 and produced 270 t of U. The roll front subtype is found in the Los Mogotes Colorados deposit (La Rioja province) which is hosted by Carboniferous continental sandstones[14].

The uranium mineralisation is also found in the veins and disseminated episyenites within peraluminous leucogranites of the Sierras Pampeanas (Cordoba and San Luis provinces). These granites are Devonian – Carboniferous and the related deposits are comparable to those from the Middle European Variscan chain [15][16][17].
There is also another vein-type uranium deposit located in a metamorphic basement in the periphery of high potassium calcalkaline granites (Franca deposit, Sierras Pampeanas Noroccidentales, Catamarca province) [18][19]. The mineralisation control is mainly structural and the speculative resources have been evaluated with 1 500 t U at a grade of 0.3 % U.

More recently, the pedogenetic calcrete type has been studied in the area of Laguna Sirven (Santa Cruz province) [20][21]. The speculative resources here are about 1 000 – 1 500 t U at 200 ppm U.

3. Final considerations

It can be pointed out that the existence of favourable basins and different uranium mineralisation models provide promising conditions to explore new uranium resources. In this context, the uranium mineralisation related to continental sandstones and volcanic and caldera-related appear as the most interesting exploration targets, with current identified resources (16,060 t U) associated to these two models.

ACKNOWLEDGEMENTS

This contribution attempts to sum up in a few words several studies that were conducted with funding from the National Atomic Energy Commission (Argentina). The author is grateful to his institution for
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REFERENCES


Abstract. Uruguay, the smallest country of South America, without domestic reserves of fossil fuel but uses this source of energy to meet over 50% of its energy requirements. In order to reduce the country's dependence on imported fuel, the Government of Uruguay gives high priority not only to the use of renewable energy resources, including biomass, wind and small hydropower but also to the exploration of new local energy sources including uranium. In 2007 prospecting for uranium resumed after seventeen years of inactivity. Presently Uruguay is analyzing the legal framework, making adjustments to the Mining Code and determining which entity will be acting as a governmental counterpart for this activity. At the same time work is in progress for identifying areas for uranium exploration and establishing terms of references for future contracts with international companies interested in conducting exploration. In this paper forty years of the uranium exploration history in Uruguay and the future directions are briefly described.

1. Introduction

Background

Uruguay (33° S, 55° W) has a population of 3,241,003 inhabitants and a surface area of 176,220 square kilometers and is the smallest country in South America.

Uruguay has no fossil energy resources, but uses the fossil sources to meet over 50% of its energy requirements. This is supplemented by hydroelectric, biomass and other minor energy sources (Fig. 1) [1].

Uruguay depends on hydropower (installed capacity 1,538 MW) and on thermal power plants (presently about 1,100 MW). On an average, hydroelectricity supplied approx. 80% of the electricity demand. Due to erratic rainfall and droughts, combined with increasing energy demand, hydropower
production is no longer considered sufficient. At present, peak power demand is approx. 1700 MW, growing 3% annually.

Since 2000, energy supply from Argentina and Brazil were negotiated as firm power and back-up contracts. However, the transmission capacity from Brazil is small (70 MW), while delivery from Argentina, based on the cheap supply of natural gas, reduced since 2004 due to the energy crisis in that country and the soaring price of natural gas.

In response, Uruguay's national electricity company (UTE), has reformulated the Expansion Plan 2006-2010 to add 500 MW new thermal capacity suitable for fuel-switching (natural gas and fuel oil), in order to match peak electricity demand and as a back-up when hydropower falls short. As part of this plan, the first 300 MW plant at “Punta del Tigre” has been brought online. The projected remaining 200 MW will consist of generators suitable for fuel oil, diesel and natural gas; an LNG regasification project is being considered to improve the reliability of gas supply.

In 2007-2008, UTE has also entered into power purchase agreements (PPAs) to buy electricity from cogeneration units operated by the large paper mills operating in the country. While UTE's average production costs remain fairly low due to the large share of hydro base power, the marginal generating costs are estimated at US$ 200-280 per MWh, depending on the reference oil price.

In order to reduce the country's dependence on imported fuel, the Government of Uruguay gives high priority not only to the use of domestic energy resources, including biomass, wind and small hydroenergy but also to the exploration of new local energy sources including uranium [2].

The use of domestic energy resources is one of the main pillars of the energy strategy of the Government of Uruguay. The National Electricity Law No. 16.832 provides a framework for an open market, allowing private operators access the grid (1997). It is significant that the Nuclear Power in Uruguay is prohibited by Article 27 of the above mentioned Law [3].
2. History of uranium exploration in Uruguay

1949 to 1989

Uranium prospecting in Uruguay, began in 1949 as a government investigation. During 40 years were developed in an ongoing activity and it is possible differentiate four distinct phases in terms of:

i) Systematic of efforts
ii) Methodology
iii) Infrastructure and provision of Human Resources
iv) Source of investment

Table 2 details the 4 different stages and the characteristics of them.

Table. 2. Phases of prospective uranium in Uruguay from 1949 to 1989

<table>
<thead>
<tr>
<th></th>
<th>Systematic</th>
<th>Methodology</th>
<th>Infrastructure</th>
<th>Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1949-1959</td>
<td>Isolated projects</td>
<td>ANCAP-UTE (gov)</td>
<td>ANCAP-UTE(gov)</td>
<td>ANCAP-UTE(gov)</td>
</tr>
</tbody>
</table>

As a results of activities carried out from 1949 to 1989 was possible acquire the following information:

i) Systematic geological information base

ii) Identification of priority areas

Figures 3 and 4 show the main information associated with the development of this first Phase.
2007 onwards

After seventeen years of inactivity in this field, the decision to resume uranium prospecting activities in Uruguay was taken. By the order of the President of the Republic a "call for expressions of interest in the conclusion of contracts for prospecting, exploration and exploitation of uranium ore in the national territory" was carried out. Several bids were received from leading international companies which were assessed [4].

In the year 2008 an interdisciplinary group composed by the Department of Energy and Nuclear Technology, the Department of Mining and Geology, the National Radiation Regulatory Authority, the Department of Environment and the Ministry of Economy and Finance was established.

FIG. 4. Overview of uranium exploration in Uruguay.
The main goal of this group is to set up the basis for the bidding activities related to prospecting, exploration and exploitation of uranium in Uruguay [5].

This group has defined two stages in this activity:

1) Prospecting
2) Exploration and exploitation

Competitive bidding phase for prospecting activities is expected in the second half of 2009.

3. **Ongoing activities**

Presently the following activities are on track:

i) Analyzing the adequacy of the legal framework and making adjustments to the Mining Code [6].

ii) Identifying areas that will be taken up for Prospecting.

iii) Determining the government entity that will be acting as a counter part of this activity.

iv) Establishing terms of references for future contracts with companies interested in conducting prospecting, exploration and exploitation of uranium.

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**REFERENCES**

Uranium and REEs resources in South Eastern desert of Egypt

M. E-A. Ibrahim

Nuclear Materials Authority, Egypt

E-mail address of main author: dr_mahmadi@yahoo.com

Abstract. Egypt started prospecting and regional exploration for radioactive raw materials since several decades. This resulted in the discovery of some low grade U- occurrences which are related to various geologic formations such as; vein-type (G. El-Missikat), metasomatised granites (G. Um Ara), shear zones in calc-alkaline granite and inter-mountain basin (G. Gattar) and surficial type uranium deposit in sedimentary rocks (Sinai). In 2002, NMA exploration activities in the South Eastern Desert resulted in the discovery of a) hot paragneiss (Abu Rusheid area) cut by discontinuous shear zones and b) metamorphosed sandstone-type uranium deposits (Sikait area). Abu Rusheid- Sikait area (ASA) is located at the South Eastern Desert, 50 km southwest of Marsa Alam from the Red Sea coast. Two nappes are seen; ophiolitic nappe (mafic– ultramafic rocks) and arc assemblages nappe (metapelites, cataclastics, metavolcanics and tonalite rocks) separated by mélange rocks. ASA is traversed by channel-ways represented by strike slip faults (ENE-WSW, NNW-SSE, N-S and NNE-SSW) and post-magmatic activities (lamprophyre -dykes). The cataclastic rocks in Abu Rusheid (3 km²) are intruded by hot and depleted granites (highly fractionated calc-alkaline granites and peraluminous granites respectively). The cataclasites are classified into protomylonite, mylonite, ultramylonite and quartzite with gradational contacts. Quartzite are exposed in two locations at Sikait area: the first one elongated NW-SE (1.8 km in length, 100-400 m in width) whereas the second one covers 0.5 km². Hot highly fractionated calc-alkaline granites (U ranges from 20-50 ppm) intrudes and surrounds the quartzite. Two brecciated discontinuous shear zones (NNW-SSE and ENE - WSW) crosscut the cataclastic rocks. Lamprophyre dykes (0.5-1.0 m in width, 0.5-1.0 km in length) with REEs, Zn, U, Cu, Sn, W, Ni & Pb mineralization are emplaced along the shear zones. Uranium contents range from 500-1 500 ppm. Uranium minerals (uranophane and beta-uranophane, kasolite, torbernite, autunite and meta-autunite), sulfides and molybdenite are common in quartzites and lamprophyre dykes, whereas uranophane and uranothorite coating in the foliation planes are common in Abu Rusheid cataclastic rocks. The lamprophyres have abnormal abundance of REEs (up to 1.5%) with average ΣLREE/ΣHREE ratio equal to (0.14). The HREE enrichment is attributed to heavy minerals (e.g. xenotime, fergusonite, zircon and fluorite). The lamprophyre is characterized by reverse fractionated REE patterns [(La/Yb)N= 0.12] and pronounced negative Eu anomalies (Eu/Eu*= 0.08) with HREE enrichment [(Gd/Lu)N= 0.80]. The lamprophyres are mantle derived and enriched in CO₂ and volatiles. Alteration processes in lamprophyres (illite, smectite, hematitization, sulfidization, silicification and flouritization) acted as physical and chemical traps for the mineralization.

1. Introduction

The common Egyptian uranium occurrences are mainly: vein-type (G. El-Missikat), metasomatised granites (G. Um Ara), shear zones in calc-alkaline granite and inter-mountain basin (G. Gattar) and surficial type U-deposit in sedimentary rocks (Sinai). In 2002, NMA exploration activities for uranium resources were focusing on the South Eastern Desert of Egypt; these works resulted in the discovery of both; a) hot paragneisse (Abu Rusheid area) cut by discontinuous shear zones and b) metamorphosed sandstone-type uranium deposits (Sikait area).

Abu Rusheid area has been studied by many authors such as [1][2][3][4]. They consider the rocks of Abu Rusheid area are of sedimentary origin (psammitic gneiss). Ibrahim et al. [5] classified these rocks into cataclastic (protomylonites, mylonites, ultramylonites and silicified ultramylonites).
Lamprophyres can be divided into calc-alkaline and alkaline lamprophyres. Calc-alkaline lamprophyres are generally characterized by large absolute contents in REE and other incompatible trace elements as well as strong LREE enrichment suggesting in some cases a genetic link among these types [6]. Lamprophyres are fine-grained hypabyssal rocks, occurring typically in thin dykes or sills. They are strongly porphyritic, with mafic silicates occurring in euhedral crystals of two generations; feldspars are confined to a fine-grained groundmass, but sometimes are found as phenocrysts. Chemically lamprophyres have low SiO2 (mostly 40 to 47 %), high (MgO + FeO) and (Na2 + K2O) [7].

In 2002, the Nuclear Materials Authority started studying the Abu Rusheide area through project. No previous studies have been carried out on the shear zones hosted lamprophyre bearing-REEs and U in Wadi Abu Rusheide, as well as the new discovery of quartzite rocks at Wadi Sikait, before the project.

2. Geologic setting

Abu Rusheide-Sikait granitic pluton elongated in NW-SE (12 km long) and thinning in NE-SW (3 km width) forms a lozenge shape or fish eye-like shape (Fig. 1). The southern part of the pluton is surrounded by layered metagabbros taking the trail of pluton shape. The opposite trend of the granitic pluton (NW) is thinner giving rise to the tip of pluton shape. The metamorphosed sandstones are represented the cap rock for the cataclastic rocks (occupy the core of granitic pluton) and also cover the western part of Sikait upstream (400 m in width, 2 km in length) in the form of boat float on porphyritic granite. The fish eye-like shape is surrounded by mafic ultramafic rocks (meta-peridotites, serpentines, talc carbonate, metapyroxenites and metagabbros) and seem to be a closed basin. The mafic ultramafic rocks are thrust over the ophiolitic mélangé. Recumbent folds are common at the contact surface (thrust plane) between the over-thrust rocks and the down thrusted ones. Sikait area is traversed by strike slip faults trending NNW-SSE, WNW-ESE and NE-SW.

FIG. 1. Landsat image (TM, band 7, 4, 2) for Abu Rusheide – Sikait area, South of Eastern Desert, Egypt.
A- Abu Rusheid area

The tectonostatigraphic sequence of the Precambrian rock units of Abu Rusheid area (Fig. 2) are arranged as follows: (1) Ophiolitic mélange, consisting of ultramafic rocks and layered metabasalts set in metasediment matrix; (2) Cataclastic group, consisting of protomylonites, mylonites, ultramylonites and silicified ultramylonites; (3) Mylonitic granites; (4) Post-granite dykes and veins [8].

FIG. 2. Geologic map of Abu Rusheid area, South of Eastern Desert, Egypt.
The layered metagabbros are thrusted over ophiolitic mélange. Recumbent folds are common at the contact surface (thrust plane) between the over-thrusted ophiolitic mélange and the down-thrust cataclastic rocks. Abu Rusheid area is traversed by strike slip faults trending ENE-WSW, NNW-SSE, N-S and NNE-SSW. The main varieties which constitute the cataclastic rocks (3 km²) are: a) protomylonite, b) mylonite, c) ultramylonite and d) silicified ultramylonite (quartz >90 in vol. %) with gradational contacts. The cataclastic rocks of Abu Rusheid area are highly sheared, banded, highly gneissose (N-S) and characterized by bedding-parallel digenetic foliations defined by elongate detrital quartz cross-cut by perpendicular shear zones (NNW-SSE and ENE-WSW). The shear zones are discontinuous, brecciated, highly tectonized and dissected by strike-slip faults with a minor displacement (Fig. 3). The lamprophyre dykes vary in their composition and are intruded by pegmatite pockets and quartz vein. Zinc, copper, sulfides, fluorite, smectite-kaolinite, goethite, magnetite, limonite, hematite and manganese dendrites are present as thin films along fractures planes and boxworks in lamprophyre clarify the epithermal events and reducing regime. Many boxworks are formed as a result of leaching processes and are filled by calcite, secondary quartz and base metals (Fig. 4).

![Image](image-url)

**FIG. 3.** a) Detailed geologic map of lamprophyre (L1), Abu Rusheid area; b) Detailed geologic map of lamprophyre (L2), Abu Rusheid area; c) Detailed geologic map of L3 (altered) and L5 (fresh) lamprophyre dykes, Abu Rusheid area.
FIG. 4. View showing boxworks filled with (a) radial secondary U-minerals, (b) corona texture include from inner to outer: calcite, hematite and secondary U-minerals and (c) carbonate surrounded by secondary U-mineral in N-S lamprophyres.

Table 1 represents paragenetic diagram of primary and secondary minerals in cataclastic rocks and lamprophyres modified after [9].

Microscopically, lamprophyre is mainly composed of plagioclases, amphiboles, phlogopite, relics of pyroxenes and K-feldspar phenocrysts embedded in fine-grained groundmass. Xenotime, fluorite, chlorite and opaques are accessories. Carbonate, quartz, jarosite, pyrite, epidote, sericite and clay are secondary minerals. Pyrite is easily oxidized by ground water in the presence of oxygen to produce either ferric oxide or its hydrate analogy.

Uranium Map

All U-contents more than 200 ppm are excluded. The ophiolitic mélange rocks have eU-content less than 1 ppm, whereas Wadi deposits and mylonitic two mica granites ranges from 8-30 ppm eU. The cataclastic rocks are characterized by extremely high eU-contents reaches its maximum values (>210 ppm up to 1 500 ppm) (Fig. 5). The uranium anomalies trends follow the main structural trends within the cataclastic rocks (E-W and N-S fault zones).
FIG. 5. Isoconcentration map showing the distribution of eU-contents in Abu Rusheid area.
Thorium Map

All Th-contents more than 700 ppm are excluded. The eTh-contents vary within the cataclastic rocks, where it increases from ultramylonites through mylonites to protomylonites (50 - >650 ppm). The thorium surface distribution map (Fig. 6) was useful in defining thorium enrichment zones. These zones are recommended as follow-up targets for potential heavy rare metals deposits.

FIG. 6. Isoconcentration map showing the distribution of eTh-contents in Abu Rusheid area.
The cataclastic samples show moderately (Eu/Eu* = 0.11) whereas the lamprophyre samples show low value (Eu/Eu* = 0.08). The ΣLREE/ΣHREE (Table 2) is enriched in cataclastic rocks (0.47) compared with lamprophyres (0.14) and wall zone (0.33). The HREE enrichment is attributed to some heavy minerals (e.g. xenotime, astrocyanite, fergusonite, zircon and fluorite), whereas LREE enrichment is related to the presence of allanite and monazite.

Table 1. Paragenetic diagram of primary and secondary minerals in cataclastic rocks and lamprophyres modified after [9][10][11].

<table>
<thead>
<tr>
<th>Minerals</th>
<th>Stage</th>
<th>Cataclastic rocks</th>
<th>AL</th>
<th>FL (L5)</th>
<th>Primary mineralization</th>
<th>Secondary mineralization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrite; (FeS2)</td>
<td></td>
<td>L1+L2</td>
<td>L3+L4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sphalerite; [(Zn,Fe)S]</td>
<td></td>
<td>✓✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chalcopyrite, (CuFeS2)</td>
<td></td>
<td>✓✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silver (Ag)</td>
<td></td>
<td>✓✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galena; (PbS)</td>
<td></td>
<td>✓✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cassiterite; (SnO2)</td>
<td></td>
<td>✓✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Litharge; (PbO)</td>
<td></td>
<td>✓✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Bismuthinite; (Bi2S3)</td>
<td></td>
<td>✓✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uranophane; (CaO.2(OH).2SiO2.H2O)</td>
<td></td>
<td>✓✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kasolite; [Pb(UO2)(SiO3)(OH)2]</td>
<td></td>
<td>✓✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autunite; [Ca(UO2)(PO4)2.8H2O]</td>
<td></td>
<td>✓✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Torbernite; [Cu(UO2)(PO4)2.8H2O]</td>
<td></td>
<td>✓✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mn-Frankilinite;</td>
<td></td>
<td>✓✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>[(Zn,Mn+2,Fe+2)(Fe+3,Mn+3)2O4]</td>
<td></td>
<td>✓✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Woodruffite; (Zn,Mn+2+Mn2+Fe+2)(Fe+3,Mn+3)2O4</td>
<td></td>
<td>✓✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Columbite; [(Fe,Mn)NbO6]</td>
<td></td>
<td>✓✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thorite; (ThSiO3)</td>
<td></td>
<td>✓✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uranothorite; [(Th,U)SiO4]</td>
<td></td>
<td>✓✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zircon; (ZrSiO4)</td>
<td></td>
<td>✓✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xenotime; (YPO4)</td>
<td></td>
<td>✓✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluorite; (CaF2)</td>
<td></td>
<td>✓✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scheelite; (CaWO4)</td>
<td></td>
<td>✓✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tourmaline</td>
<td></td>
<td>✓✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limonite</td>
<td></td>
<td>✓✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hematite</td>
<td></td>
<td>✓✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Magnetite</td>
<td></td>
<td>✓✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Goethite</td>
<td></td>
<td>✓✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

AL= altered lamprophyre dykes cut cataclastic rocks (L1+L2+L3+L4)
FL= fresh lamprophyre dyke cut monzogranite (L5)

Cataclastic samples exhibit fractionated REE patterns [(La/Yb)N=0.27, an average] and display relatively flat LREE [(La/Sm)N=2.2 an average] with relatively enriched HREE [(Gd/Lu)N=1.2 an average] and negative Eu anomalies (Eu/Eu*= 0.11) (Table 3). The lamprophyre samples are characterized by relatively fractionated REE patterns [(La/Yb) N=0.12 an average] and large negative Eu anomalies (Eu/Eu*= 0.08 an average) with HREE enrichment [(Gd/Lu)N=0.80 an average]. It appears that the hematitization process have caused the enrichment of the REE especially HREE in lamprophyre than cataclastic rocks.
Table 2. Radioelement distribution of eU, eTh and eU/eTh along lamprophyres (L1, L2 and L3).

<table>
<thead>
<tr>
<th>Shear zone No.</th>
<th>N</th>
<th>eU (ppm) Range</th>
<th>eTh (ppm) Range</th>
<th>eU/eTh Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Av.</td>
<td>Av.</td>
<td>Av.</td>
</tr>
<tr>
<td>L1</td>
<td>419</td>
<td>40-1200</td>
<td>20-400</td>
<td>0.5-4</td>
</tr>
<tr>
<td>L2</td>
<td>114</td>
<td>10-1700</td>
<td>40-1600</td>
<td>0.2-3</td>
</tr>
<tr>
<td>L3</td>
<td>96</td>
<td>10-1000</td>
<td>30-1700</td>
<td>0.2-0.9</td>
</tr>
</tbody>
</table>

N: Numbers of measurements

Table 3. Average of rare earth elements (REE) data of the cataclastic, lamprophyre and wall zones, Abu Rusheid area.

<table>
<thead>
<tr>
<th>REE</th>
<th>Cataclastic N=11</th>
<th>lamprophyres N=24</th>
<th>Wall zones N=5</th>
</tr>
</thead>
<tbody>
<tr>
<td>La</td>
<td>12</td>
<td>199</td>
<td>15</td>
</tr>
<tr>
<td>Ce</td>
<td>29</td>
<td>192</td>
<td>76</td>
</tr>
<tr>
<td>Pr</td>
<td>5</td>
<td>110</td>
<td>6</td>
</tr>
<tr>
<td>Nd</td>
<td>14</td>
<td>340</td>
<td>20</td>
</tr>
<tr>
<td>Sm</td>
<td>3</td>
<td>141</td>
<td>8</td>
</tr>
<tr>
<td>Eu</td>
<td>0.13</td>
<td>4</td>
<td>0.7</td>
</tr>
<tr>
<td>Gd</td>
<td>5</td>
<td>167</td>
<td>12</td>
</tr>
<tr>
<td>Tb</td>
<td>1</td>
<td>71</td>
<td>6</td>
</tr>
<tr>
<td>Dy</td>
<td>12</td>
<td>689</td>
<td>52</td>
</tr>
<tr>
<td>Ho</td>
<td>3</td>
<td>174</td>
<td>15</td>
</tr>
<tr>
<td>Er</td>
<td>14</td>
<td>843</td>
<td>39</td>
</tr>
<tr>
<td>Tm</td>
<td>3</td>
<td>137</td>
<td>9</td>
</tr>
<tr>
<td>Yb</td>
<td>28</td>
<td>1018</td>
<td>60</td>
</tr>
<tr>
<td>Lu</td>
<td>5</td>
<td>151</td>
<td>9</td>
</tr>
<tr>
<td>Y</td>
<td>61</td>
<td>3770</td>
<td>179</td>
</tr>
<tr>
<td>ΣREE</td>
<td>195</td>
<td>8006</td>
<td>506</td>
</tr>
<tr>
<td>ΣLREE</td>
<td>62</td>
<td>986</td>
<td>125</td>
</tr>
<tr>
<td>ΣHREE</td>
<td>133</td>
<td>7020</td>
<td>381</td>
</tr>
<tr>
<td>ΣLREE/ΣHREE</td>
<td>0.47</td>
<td>0.14</td>
<td>0.33</td>
</tr>
<tr>
<td>(La/Yb)N</td>
<td>0.7</td>
<td>0.12</td>
<td>0.16</td>
</tr>
<tr>
<td>(La/Sm)N</td>
<td>2.2</td>
<td>0.92</td>
<td>1.2</td>
</tr>
<tr>
<td>(Gd/Lu)N</td>
<td>1.2</td>
<td>0.80</td>
<td>1.7</td>
</tr>
<tr>
<td>Eu/Eu*</td>
<td>0.11</td>
<td>0.08</td>
<td>0.2</td>
</tr>
<tr>
<td>Ce/Ce*</td>
<td>1.3</td>
<td>0.4</td>
<td>2.4</td>
</tr>
</tbody>
</table>

N: Number of samples analyzed for REEs (ppm)

B- Sikait area

Detailed geologic maps for the two metamorphosed sandstone at W. Sikait were constructed (Fig. 7) on the base of a grid pattern 25 x 25 m. The exposed rocks are arranged as follows: 1) ophiolitic mélangé (consists of mafic-ultramafic fragments set in metapelites matrix); 2) metamorphosed sandstones; 3) gabbros, 4) granitic rocks (porphyritic biotite granites and mylonitic biotite granites) and 5) post-granite dykes (lamprophyres) and veins (quartz).

The metamorphosed sandstone rocks are fine–grained, white in color, highly sheared, banded, less foliated and cross-cut by lamprophyre dykes (NW-SE, N-S and E-W) and quartz veins (NNW-SSE, NNE–SSW and E-W). The metamorphosed sandstone rocks crop out in W. Sikait at two locations. The first outcrop (major) is located west the upstream of W. Sikait (Fig. 3), whereas the second outcrop (small area) is located at the bending of W. Sikait.
The first metamorphosed sandstone outcrop covers a relatively larger area than the second exposure, with low to medium peaks, highly tectonized, elongated in NW-SE (2 km in length and thinning layering in NE-SW (150-500 m in width) forming float-boat-like shape (Fig. 8) and intruded by fertile porphyritic granite (20 ppm eU) and lamprophyre dykes. The metamorphosed sandstone rocks are traversed by three sets of strike-slip faults trending NW-SE, NNW-SSE and NNE-SSW and one set of dip-slip fault trending ENE-WSW. These faults control the shape and setting of metamorphosed sandstone rocks, where the maximum elongation of metamorphosed sandstone is controlled by NW-SE sinistral strike-slip fault set. The metamorphosed sandstones range in color from pale white to milky white, generally uniform in texture and composed of fused quartz grains.

The rock shows relics of primary bedding, banding and obvious foliation in NW-SE with angle of dip 35°/SW. It has granular appearance on the weathered surface with common vugs (boxworks) filled with secondary mineralization but along a broken surface the quartz grains are usually split. The fractures are usually open spaced, filled with secondary uranium and molybdenite. The common alteration products are represented by hematitization and manganese dendrites. Semi-angular to elongated rock fragments (mainly metagabbros in composition) are enclosed in metamorphosed sandstones, manifesting the greywacke composition. Lamprophyre dykes were emplaced relatively in NW-SE, N-S and E-W trends cutting both metamorphosed sandstones and porphyritic granites. The trend of lamprophyre dykes is concordant with the main structural trends that control setting of the metamorphosed sandstones. These dykes are altered, fine-grained, black grey in color, discontinuous and vary in thickness from 0.5 to 2 m and up to 1.4 km in length.

The second metamorphosed sandstone outcrop, covers a small area (0.5 km), forming low terrain and intruded by the granites. Some scattered goethite and yellow limonite after sulfide crystals are observed on the weathered surface of the rocks. The metamorphosed sandstones are whitish in color, sheared, foliated (NE-SW) and cut by two types of quartz veins. A) barren quartz veins (E-W, N-S and NNE-SSW) dislocated by N-S strike slip faults and cross-cut the foliation planes of metamorphosed sandstones and b) quartz vein (NE-SW)-bearing mineralization ( wolframite, cassiterite and xenotime) visible to the naked eye. It varies from 1-2 m in width and extends for 15 m in length parallel to the foliation planes. Microscopically, the metamorphosed sandstone rocks are fine to medium-grained of whitish grey in color and vary from graywacke to arkosic in composition. The characteristic minerals which recorded in metamorphosed sandstone at Sikait are listed in Table 4.

<table>
<thead>
<tr>
<th>Minerals</th>
<th>Metamorphosed sandstone</th>
<th>Lamprophyre dykes</th>
<th>Quartz vein</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-minerals</td>
<td>Uranophane, β-uranophane, kasolite and autunite.</td>
<td>Uranophane</td>
<td>-</td>
</tr>
<tr>
<td>Th-minerals</td>
<td>-</td>
<td>Thorianite</td>
<td>-</td>
</tr>
<tr>
<td>U-bearing minerals</td>
<td>Smarskaite</td>
<td>Bunsenite, pyrite and roasite</td>
<td>Wolframite and cassiterite Uraniferous xenotime and piedmotite</td>
</tr>
<tr>
<td>Base metals</td>
<td>Bunsenite, ilsemanite, galena and nimite Zircon, garnet, fluorite, uraniferous xenotime, and REE-silicate</td>
<td>Wolframite and cassiterite Uraniferous xenotime and piedmotite</td>
<td></td>
</tr>
<tr>
<td>Accessory minerals</td>
<td>Ilmenite</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Equivalent U-contour map**

Matching the equivalent uranium contour map with geologic map reveals two levels of radioactivity. The first level has the lower value (≤ 15 ppm eU) and coincides with porphyritic granites with no specific trend. The second level ranges in intensity from 15 to 85 ppm eU and is associated with metamorphosed sandstones (Fig.8). The abnormal eU contents in metamorphosed sandstones were
relating to high Na- and K-metasomatism. The eU anomalies also reflect visible secondary U-
remobilization along the structural trends (NW-SE, N-S and E-W). The tectonic trends act as good
traps for U–rich fluids or U-ores.

**Chemical U-contour map**

Matching the chemical uranium contour map (Fig. 9) with geologic map reveals two levels of
radioactivity. The first level has the lower value (≤ 280 ppm U) and coincides with NE side of
metamorphosed sandstones towards W. Sikait. The second level ranges from 280 to 480 ppm U and
close contact with fertile porphyritic granites.

![Chemical U-contour map](image)

**FIG. 7. Detailed geologic maps for the metamorphosed sandstone at W. Sikait.**

The abnormal U contents in metamorphosed sandstones were relating to high shearing, tectonic and
mobilization. The chemical U content is five times equivalent U content, whereas the chemical U
content ranges between 60 to 480 ppm, while the equivalent U ranges between 15 to 85 ppm. This
conclusion supports the youngest age (less than million years) for U mineralization.

**Equivalent Th-contour map**

Correlation between equivalent Th-contour map (Fig. 10) and geologic map of Sikait indicates two
levels of eTh -contents. The first level has the lower value of eTh-content (≤ 40 ppm eTh) and
coincides with porphyritic granites, whereas the second level ranges from 40 to 85 ppm eTh and is
associated with metamorphosed sandstones.
FIG. 8. Equivalent uranium contour map for metamorphosed sandstone Sikait
FIG. 9. Chemical uranium contour map for metamorphosed sandstone Sikait.
3. Conclusions

A Abu Rusheid area

1- Lamprophyre textures are bladed and banded colloform-crustiform. These textures are common in epithermal base metals, indicative of boiling event and rapid deposition (Hedenquist et al., 1995).

2- The REEs minerals are represented by xenotime, astrocyanite, fergusonite, allanite, monazite and zircon.

3- The remarkable enrichment in carbonate, sulfide and fluorite in lamprophyre, may propose complexation of REEs with HCO3-, CO3-2, SO4-2 and F-. During ascending of hydrothermal solutions in shear zones, the sudden change in the physico-chemical conditions causes the REEs complexes breakdown and the precipitation of the REEs.
4- The lamprophyre is mantled-derived with high temperature and volatiles, as well as, CO2. The REEs are often transported (either along the foliations and banding of the cataclastic rocks or ascending from hidden peraluminous granites) to the shear zone and precipitated with other rare metals, such as W, Pb, Zn, Ag and Cu on boxworks and clay minerals.

5- The hematization process (a good trap for REEs) has caused the enrichment of the HREEs-bearing lamprophyre samples than cataclastic rocks. Precipitation of hematite probably decreased the pH of the solution and rising acidic fluids. The sudden change in the pH and temperature of the fluids will lead to destabilization of rare earth complexes favouring their deposition.

6- The presence of smectite-illite indicates a rather high temperature epithermal environment, higher than 200º C. The mixing of volatile fluids with meteoric water and fluid-wall rock interaction result in changes in pH and oxygen activity.

7- The U-mineralization has been formed as product of the hydrothermal events. It includes secondary U-minerals (uranophane and beta-uranophane, kasolite, torbernite, autunite and meta-autunite) in addition to U-bearing minerals (astrocyanite, betafite and fergusononite).

B- Wadi Sikait area

The metamorphosed sandstone represents the target for uranium and associated minerals. It extends NW-SE for about 2.0 Km in length and ranges from 100-400m in width. The uranium minerals include uranophane, beta-uranophane, kasolite and autunite, and they are affected by some factors:

1- The presence of mineralizing source represented in our opinion by both cataclastics (west the mapped area) and hot contact granitic rocks (20 ppm eU).

2- The hydrothermal solutions play a major role in dissolution, transportation and deposition of minerals (e.g. wolframite, U-minerals, fluorite, ilsemnite and uraniferous xenotime).

3- The good open fracture system which represented by shearing, foliation, and bedding, and acts as good pathways for the solutions.

4- The mobilization and migrated uranium from the hot uraniferous porphyritic granite towards metamorphosed sandstone is due to the heat of metamorphism, emplacement of both lamprophyre dykes and granites.

5- The effect of post depositional (diagenesis) and alteration processes (sodic, potassic and fluoritization) respectively as well as the reducing condition (sulfides and graphite).

REFERENCES


Niger's uranium resources and potential

M.O. El Hamet, Z. Idde

Research Centre for Geology and Mining, Niamey, Niger

Abstract. The first important uranium shows were discovered in Niger in 1958 by the French BRGM in Azélik; two other French companies specializing in the nuclear fuel cycle, CEA and COGEMA, also carried out exploration activities from 1959 to 1980 in the entire, high potential, Tim Mersoï basin, leading to the discovery of other uranium shows and about twenty world-class deposits. The Air basement and two other Palaeozoic basins, Djado and Tafassasset, also have good potential. Niger’s uraniferous provinces comprise 360,000 km². In 1971, SOMAIR began uranium production, followed in 1978 by COMINAK. Both mines are operated by AREVA NC, and they have already produced 110,000 tU in the last forty years, and their current production is 3,200 tU/y. Following a spectacular increase in the price and demand for uranium, exploration activities that were interrupted for more than a decade following the first uranium boom were resumed in 2002; 127 uranium exploration licences have been granted to some fifty foreign mining companies in Niger. All the economic mineralizations are located near the Arlit-In Azaoua fault in detritic sedimentary rocks of the Carboniferous to Cretaceous eras: conglomerates, sandstones and siltites rich in organic material and sulphides. Sedimentological, stratigraphical, redox phenomena and tectonic evolution of the northern Niger region all played an important role in the genesis of Niger uranium deposits. Uranium is mainly found in its primary mineral forms: pitchblende - uraninite group and coffinite. In Imouraren, Imca 25 and Azélik, however, the secondary minerals (gummite, uranotile tyuyamunite, carnotite) predominate. The average grades of the economic deposits vary from: 0.08 to 0.6% U, with a maximum of up to 3% U. Notwithstanding the 110,000 tU already extracted, considerable resources 500,000 tU still remain in Niger (140,000 tU recoverable for less than US $50/lb). Near the Arlit-In Azaoua fault and its satellite faults, detailed exploration using modern, efficient, methods could lead to the discovery of other deposits. Production in the Imouraren (240,000 tU) and Azélik (14,000 tU) deposits is under way and, with total production expected to reach around 10,000 tU/year, this should bring Niger up into second place amongst worldwide uranium producers.

1. Introduction

The first shows of uranium in Niger were discovered in 1958 by the BRGM at Azélik in the Agadez region. Subsequently, the CEA and COGEMA, two French companies specializing in the nuclear fuel cycle, conducted systematic exploration of the entire Tim Mersoï and Djado basins, located in the northern desert of the country (Fig. 1 and 2).

From 1973 to 1980, following the spectacular increase in uranium price and demand, several mining and oil companies (Cogema, Conoco, Pan Ocean, BP, Esso, OURD, IRSA, PNC, etc.) obtained licences for uranium exploration in Niger. These efforts met with great success through the discovery of considerable total resources estimated at more than 500,000 tU and a known potential in the three large sedimentary basins of Tim Mersoï, Djado and Tafassasset, as well as the Air basement, which form one of the largest uraniferous provinces in the world covering a total area of 360,000 km². About twenty world-scale, economic deposits have been discovered there and as a result Niger has been well placed amongst uranium producers for some forty years. The exploitation of two new deposits (Imouraren and Azélik), with production of approximately 10,000 tU/year, will make Niger the world’s number two producer in two years' time. Since 2002, 127 exploration licences have been issued to some fifty mining companies [1].
2. Geological framework

Niger is a Sahel country situated in the heart of West Africa sharing common borders with Algeria, Libya, Chad, Nigeria, Benin, Burkina Faso and Mali (Fig. 1). Geologically speaking, five large basins (Tim Mersoï, Chad, Djado, Tafassasset and Iullemmeden) overlie the basement in three large regions. The present geology of Niger derives from its belonging to the West African craton and the Central African mobile zone. The major structural regions are:

- Liptako-Gourma basement, which represents the extreme northeast of the Man Ridge and extends from the Burkina Faso border to the Niger river and beyond;
- Aïr, Damagaram-Mounio and South Maradi basement in the central part of the country;
- sedimentary basin of Niger’s western basin (Iullemmeden Basin);
- sedimentary basin of Niger’s eastern basin (Chad Basin); and
- Djado plateau in the far north-east.

2.1. Liptako-Gourma basement

The Niger Liptako covers 32 000 km² and is basically composed of Lower Proterozoic (Birimian) formations arranged in meta volcano-sedimentary belts intersected with granitoids which represent more than 60% of the total area. The green Birimian rocks are mainly those of Gorouol, Téra, Sirba and fragments of meta volcano-sedimentary rocks, the most important of which is the Makalondi slab.

2.2. Pan African basement: Aïr, Tafassasset, Damagaram-Mounio and South Maradi

These formations belong to the Pan African Upper Proterozoic chain surrounding the West African, Congo and Kalahari cratons. They could be primary sources of uranium since there are several occurrences of this metal in the Algerian Hoggar mountains.
2.3. **Air**

The Air, together with the Hoggar and Adrar des Iforas, forms the Touareg shield. The latter belongs, just like the Benin-Nigerian shield, to the Central African mobile zone affected by Pan African orogeny around 600 Ma. The Air crystalline basement outcrops over an area of 62 000 km$^2$ and comprises a central folded zone that is strongly metamorphized and invaded by Pan African granitoids, and which is separated from the epimetamorphic areas bound by the major thrust faults of Tafadek in the west and Aouzegeur in the east. The epito meso-metamorphic supracrustal formations are pre-Pan African, probably Suggarian. The molassic formation of the Proche-Ténéré, attributed to the infracambrian, is very little metamorphized and subhorizontal, and lies in unconformity on the Suggarian basement.

The subvolcanic ring complexes, from the Palaeozoic era, comprising the northern extremity of the “Younger Granites” province, sharply intersect the Suggarian basement. This magmatic activity resulted in the creation of massifs of gabbros, anorthosites, syenites and alkaline and hyperalkaline granites. The Quaternary and Tertiary volcanism is characterized by some thirty trachytic (associated with numerous basalt emissions) and phonolotic structures.

The Air structure is an anticlinorium plunging northwards. The kilometre scale, isoclinal and overturned folds to the east are the result of an E-W compression. The Aouzegeur and Tafadek thrust faults with inward dips limit a central overthrust zone from the external zones. These thrusts with an ophiolitic ridge at the base characterize a collision between the West African craton and the Central African mobile zone after Pan African oceanic closure. Also visible in the Air is a family of sinistral NW-SE faults as well as a second, more discrete, NE-SW family.

2.4. **Damagaram-Mounio and the South Maradi**

The crystalline areas of Damagaram-Mounio (26 000 km$^2$) and South Maradi (272 km$^2$) are situated in south-central Niger on an 80 km band along the Nigerian border. This constitutes the northern extremity of the Benin-Nigerian shield. It is composed of Precambrian supracrustal formations with Pan African granite intrusions, all intersected with Palaeozoic subvolcanic ring complexes.

2.5. **Ténéré basement**

It covers an area of 13 000 km$^2$ and is a SE extension of the Hoggar outcropping in the form of a narrow NW-SE band bordering the Djado basin to the west. It appears sporadically further south in the Achégour and Fachi regions. Of middle Precambrian age, it is characterized by a folded meta-volcano-sedimentary sequence intersected by granitoids.

2.6. **Tim Mersoï basin**

It covers an area of approximately 114 000 km$^2$ in the north-west part of Niger and forms part of the much larger basin of Iullemeden covering most of western Niger and Mali (Figs 2 and 3). The uranium deposits currently being exploited in Niger are all located in the Tim Mersoï basin. In the east, this basin rests on the Air basement and then becomes progressively deeper towards the west and north before starting an uplift on the In Guezzam ridge. Its eastern flank is a gentle slope to the In Azawa lineament. The sedimentation is mainly continental and marginal-littoral after the Lower Devonian. The Irhazer marly clay lacustrine deposits are located in the southern part of the basin. To the north and the west, the basin becomes deeper at the In Azawa lineament intersection; its geological history started as of the Cambrian in the Tin Séririne synclinal structure.

Over the course of the basin’s geological history, the sedimentation areas have migrated from north to south. Three large sedimentation areas have been identified as Lower Carboniferous to Lower Cretaceous:
• a Lower Carboniferous basin with successions of fluvio-deltaic floodplain deposits and marine sediments;

• a Permo-Triassic and Jurassic basin, much smaller than the aforementioned one and comprising interlayered volcano-sedimentary flow deposits in fluviatile bodies;

• a Lower Cretaceous basin invaded by lacustrine, and subsequently fluvio-deltaic, deposits.

The location of the sedimentation areas is determined by epi-orogenic movements. The basin is made up of a system of narrow, submeridian grabens and horsts, the isostatic readjustments thus leading to sediment movement from the horsts to the grabens. The deposit areas are arranged in submeridian bands alternating with paleo-domes, sometimes covered with condensed series.

The main structural zones of the Tim Mersoï basin are as follows:

• The Tin Séririne synclinorium occupying the north of the basin has an internal structure comprising a succession of numerous asymmetric anticlines and synclines;

• The Tim Mersoï graben runs along the In Azawa-Arlit lineament and extends towards the south of the Tin Séririne synclinorium;

• The southern part of the basin is made up of alternating narrow ridges and valleys in the NNE-SSW direction;

• The In Azawa-Arlit lineament zone, situated approximately 50 km from the eastern edge of the basin, is made up of a succession of narrow grabens in the north-south direction.

This basin structure is one of the important factors controlling the uraniferous mineralization as the mineralization is generally up against the flanks of paleo-domes.

2.7. Sedimentary Iullemmeden basin

This basin, with an area of 880 000 km² covers virtually all of western Niger and extends into Algeria, Mali, Benin and Nigeria. Over the course of geological time, several individual secondary basins (Tim Mersoï, Tamesna, Kandi, In Gall, etc.) formed within the main basin (Fig 2). The Cambrian to Pleistocene stratigraphic sequence is characterized by alternating deposits of marine influence and continental complexes. Palaeozoic formations outcrop all along the sedimentary margin of the Aïr, in the Tim Mersoï basin. Uraniferous mineralizations are associated with Upper Carboniferous formations, particularly with the sandstones of Guézouman, Tarat and Madaouéla. The Carboniferous also hosts coal deposits in the Anou Araren region.

The Intercalary Continental is a thick sandstone and clay series from the Permian to Lower Cretaceous era. It outcrops mainly in Tamesna, Irhazer and Téguidit. It hosts uranium- and copper-bearing mineralization levels as well as saline horizons which can be mined for salt. The Upper Cretaceous and Lower Tertiary marine formations are characterized by a succession of argillites, marls and fossil-bearing limestones with silty, sandy or gritty horizons. The Hamadian Continental is the equivalent marine Cretaceous continental and covers the Zinder and Maradi regions.

The third continental complex is the Terminal Continental following the Marine Tertiary. This thick detritic series of lignite levels and siderolithic horizons covers western Niger. The Salkadama coal deposit is found in these sequence. The Terminal Continental hosts the main iron shows and deposits known in Niger.
FIG. 2. Simplified geological map of western Niger.
FIG. 3. Lithostratigraphic scale of the south-eastern part of the Im Mersoï basin (adapted).
2.8. **Djado basin and its western flank**

It is characterized by Palaeozoic formations and the presence of Precambrian rocks on its western flank. This basin hosts occurrences of uranium and numerous interesting radiometric anomalies and gypsum, probably the most significant in Niger. The potential for other metals remains entirely unknown. The Carboniferous palaeogeography and lithologies are favourable factors for the stratiform concentration of certain base metals (Cu, Zn and Pb).

2.9. **Eastern sedimentary basin of Lake Chad**

It covers eastern Niger and extends into Libya, Chad and Nigeria. It covers the territory stretching from the Air and Damagaram-Mounio mountain backbone to the eastern border with Chad and the northern border with Libya and Algeria. It hosts Palaeozoic to Quaternary sedimentary formations. The Quaternary deposits cover most of the basin. Oil exploration activity has led to the discovery of a series of relatively deep NW-SE grabens (Kafra, Grein, Agadem, (Ténéré, Temit), West Termit and N’Gel Edji) extending some 1 000 km from the Hoggar in the north to Lake Chad in the south. The thickness of the sediments in these grabens can attain 3 000 to 4 000 m, and even 12 000 m. Significant hydrocarbon reserves have been discovered in the Termit grabens and will be exploited in the near future.

3. **Production**

In 1971, SOMAIR started uranium mining, producing 410 t/year, followed in 1978 by COMINAK. Together, these two mining companies have a production capacity of 4 500 tU/year, but have been producing an average of 3 000 tU per year for almost 40 years. In 2008, they produced 3 200 tU [1]. In 2008 and 2009, two new mining companies (SOMINA and Imouraren Ltd) obtained their licences to exploit the Imouraren and Azélik deposits, with planned production commencing in 2011 and 2012, respectively. This will propel Niger into second place amongst the world's uranium producing countries, producing around 10 000 tU/year (Fig 4). The Madaouela deposits, adjoining those of Arlit, are in the intensive development stage.

![Mining cadastral survey of Niger](Fig 4)
4. Main deposits found in Niger

The extensive survey work carried out mainly by the forerunners of AREVA NC (the French CEA and COGEMA) and Japanese companies (IRSA, OURD, PNC) in the Tim Mersoï intracratonic basin led to the discovery of some twenty economic deposits — Arlette, Ariège, Artois, Ariane, Arthur, Arni, Akouta, Akola, Ebba, Ebene, Ebal, Imouraren, Imaren, Imca 25, Irhawenzegirhan, Azelik, Madaouela, In Gall and Tinégourane. These deposits are situated in the following 5 mining areas for which a brief description is given (Fig 6):

4.1. Arlit concession

This concession, covering an area of 360 km² was granted to the French CEA, now AREVA NC, in 1968. About fifteen uranium deposits have been found there and four areas, including the main deposits, have been leased to three mining companies: SOMAIR, COMINAK and SMTT.

4.1.1. SOMAÏR and SMTT lease (55 km²)

Established in the period when the uranium price dropped, SMTT was not able to reach the production stage; first it sub-let, then ceded, its area (37 km²) to SOMAÏR. In these two areas, the following deposits have been exploited by SOMAÏR: Arlette (10 000 tU), Ariège (15 000 tU), North Taza and South Taza (10 000 tU), Takriza (4 000 tU), Tamou (6 000 tU) and Tamgak (8 000 tU). There are still three deposits that have not yet been exploited: Artoïs (17 000), Arthur, Ariane, Tabélélé (1 500 tU) [2]; exploitable resources have been discovered in the area in-between these known deposits.

The Arlit uranium deposits are located in the Lower Carboniferous sandstones of Tarat. They comprise: Arlette, which has already been mined, Ariège, being mined, Artois, Ariane, Arthur, Tamgak, Taza, Tamou, Takriza and Tabélélé. The Tarat formation which host mineralization are sandstones with argillaceous-silty intercalations and the continental platform has a fairly uniform relief. Tarat lies in erosional unconformity on the Tchinézogue argillites, covered by alternations of fine sandstone and silty argillite of Madaouela; the fine oolin argillaceous sandstones of the Arlit unit.

The uranium is located in the fine sediments of mudflats and sandstone bodies near river mouth bars. The mineralization is more or less continuously in contact with the sandstone clay alternations. In the sandstone bars it underlines the stratifications and is concentrated in the “bottom set”. The mineralization is generally represented by pitchblende and coffinite. In shallow deposits, like Arlette and Tabélélé, part of the primary minerals have been oxidized and transformed into tyuyamunite, francavillite and carnotite. In clays, part of the uranium is fixed in the form of organometallic complexes that are difficult to process.

Development and exploitation of the various deposits has led to improved knowledge of the total resources in the SOMAÏR mining zone, around 100 000 tU, of which half have already been mined. Exploration is continuing in the area and the experience gained by AREVA NC over 40 years of mining the various deposits will help to increase these resources. The Artois deposit, for which a feasibility study was approved in 2005, hosts approximately 17 000 tU (0.3% U).

Residual resources, estimated at 4000 tU, exist in the area between the various deposits and at the bottom of some quarries where mining has been suspended. Finally, there is 20 000 tU contained in the low grade ore heaps (ore grade > 0.14% U) stored during the years of recession in the uranium market. SOMAÏR resumed heap lixiviation treatment (HL) in 2009 and expects to produce up to 900 tU/year using this process. Thus, SOMAÏR has estimated total resources of 60 000 tU, of which 24 000 tU are classified as reserves that are proven to be economic under current market conditions [3].
4.1.2. **COMINAK lease (Akola and Akouta)**

Two large deposits have been found in this 22.4 km$^2$ area and are being exploited: Akouta (40 000 tU - 0.6% U) and Akola (20 000 tU - 0.5% U). The uranium deposits in the area leased to COMINAK are located in the Guézouman Carboniferous formation. This is a vast regressive floodplain delta area on a continental platform. The main mineralizations are found on the Akouta channel and its branches.

Structurally speaking, the flexure fault of Arlit-In-Azaoua North-South and in the directions N 40°, N 140° and N 80° are responsible for the isolation of the deposit zone. The uranium is essentially in the form of primary minerals present in the sandstone cement in microscopic black elements (pitchblende and coffinite) and are almost always associated. The associated elements are molybdenum and vanadium. Despite more than 30 years of exploitation, reserves still remain in the Akouta and Akola deposits, proven to be economic under current conditions, estimated at 6 000 tU with an ore grade of 0.4% U. The complementary and supplementary resources are of the order of 35 000 tU.

4.1.3. **The Afasto licence**

The Afasto licence adjoins the southern edge of the Arlit concession, covers an area of 27 325 km$^2$, and is currently held by COMINAK, which obtained a mining licence in 2005 for the Ebba deposits. The Afasto licence deposits are in the same geological setup as those of the Arlit concession and are, in particular, an extension of the Akouta deposit. They are linked to the Guézouman Carboniferous formation, which lies generally in erosional unconformity on an essentially clay-silty formation (Talak) and is covered with Tchinézogue argillites. This is a mainly sandstone formation of fluvio-deltaic origin, manifesting marked variations in thickness (40-70 m), arranged in three units:

- Bottom, heterogranular sandstones starting with an erosional conglomerate (Téléfak) with pebbles of clay, rhyolite, quartz and quartzite, embedded in a pyrite or ferruginous sandstone matrix;
- Intermediate deltaic sandstones; and
- Upper alternations of sandstone and fine clay-silty sediments.

Structurally speaking, the Afasto licence deposits are surrounded by the meridian flexure-fault of Arlit-In Azaoua and its satellites in the N 30° direction, and the Madaouela, Izérétagen, Izéguéram Mouron, Autruche and Aguelal-Zéline faults. These events have had a determining influence on uranium entrapment.

Several formations in the Afasto licence are mineralized in uranium: three levels in Guezouman, Tarat and Madaouela and the Permian to Cretaceous formations (Moradi, Teloua, Assaouas). Uranium is manifested as tetravalent (pitchblende, coffinite) and hexavalent forms associated with phosphates in the Agelal sandstones (1% U) from the Triassic era. On the contrary, in the Akouta deposit, uranium is not associated with molybdenum, but rather with vanadium. The mineralization seems to be synsedimentary and appears in the cement of sandstones and conglomerates mostly in the first 20 metres at the bottom of Guézouman. The mineralized body is situated at a depth of between 205 and 270 m with mineralized thicknesses ranging from 0.5 to 11 m. It becomes gradually deeper to the south and the west (300 to 400 m).

Mineralization controls are:

- Tectonic: role of the flexure fault of Arlit-In Azaoua and its satellites (Tekaden, Izéguéram, Izérétagen);
- Stratigraphic: link with some particular units at the bottom of Guézouman;
• Lithological: mineralization link with bottom-set sediments of sandstone bars and fine sandstones rich in organic vegetable matter, contact with the Talak; and

• Epigenetic: redox phenomena between the oxidizing waters from the Permian aquifers in contact with the reducing medium of Guézouman.

The total resources of Afasto are currently estimated at 40 000 tU with an average ore grade of 0.37% U, of which 50% (20 000 tU) are classified as economic reserves at the current uranium market price [4]. They have been located in the northern zone of the licence (Ebba deposit). These resources may increase considerably through development of the major shows of Ebala and Ebene situated less than three km further south. Complementary, supplementary and geological resources of the order of 25 000 tU may be attributed to the Ebbene and Ebala beds, which are known only from 200 to 1 600 m test boreholes. This also takes into account the fact that certain mineralized impacts are located at depths of more than 300 m.

4.2. Imouraren licence

It is situated 80 km south of the Arlit concession and covers an area of 313.5 km²; in 1963 the CEA discovered the uranium shows of Mont Imouraren in a 40 km² area. After granting of the mining licence (128 km²) in January 2009 to the Imouraren company, the remainder of the licence was called the Anou Agerouf exploration licence [5].

The Imouraren licence is situated in the eastern part of the Tim Mersoï basin. The geological formations are Carboniferous to Cretaceous continental, terrigenous, detritic formations lying on the Pan African basement dipping gently to the west. The deposit it basically linked to the Jurassic Tchirézrine II formation; this formation is confined at the top and bottom by two formations with very fine grain size distribution and low permeability, Irhazer-Assaouas and Abinky. The mineralization is concentrated in heterogranular sandstone facies of fluvial origin with intercalating levels of analcime. The sandstones of Tchirézrine are generally poorly cemented; the cement is made up of secondary silica, greenish clay, analcime, kaolinite, limonite and haematite. The primary source of uranium seems to be in the Air volcanism, as indicated by analcimolite. In addition to the standard factors (stratigraphic, sedimentological, palaeogeographical and tectonic), mineralization control seems to be the result of two phenomena: dispersion by oxidation of a syngenic mineralization and reconcentration of an epigenetic mineralization by roll type phenomena.

The Imouraren mineralization is a special case, differing from other known deposits. It is 90% composed of hexavalent secondary uranium minerals (uranotile, meta-tyuyamunite) and 10% of primary minerals (coffinite, pitchblende), appearing in sandstone cement, at the centre of analcime grains and pebbles and in epigenized vegetable debris. Uranotile (Ca(H₂O)(UO₂)₂(2SiO₄)₂·3H₂O) is the most abundant mineral and is manifested in small fibroradiated clusters underlining the stratification or filling in the imprints of vegetable debris. These uranium minerals are often associated with copper sulphides and silicates (chalocite and chrysocolle) and even with native copper; vanadium is present but often linked with chlorites in the form of montroseite.

Unlike the other deposits in the region, the Imouraren uraniferous mineralization is weakly carbonated (0.2 to 0.5% calcite). Iron minerals (pyrite, haematite, goethite), sulphates (gypsum, barytine) and phosphates (apatite) are not very abundant. Organic matter is rare or absent. The mineralization is spread over three levels in the whole sandstone facies of Tchirézrine II at a cumulative average thickness of 55 m at depths of between 105 and 165 m. Laterally, the mineralization is subdivided into three zones from north to south: Imatra, Imfout and Imola. In the west Arlit-In Azaoua flexure area, two new average size and shallow (25-35 m) deposits, called Imca 25 and Imaren, were found during recent activity.

Development of the Imouraren uranium shows between 1974 and 1977 by the COGEMA-CONOCO-ONAREM association led to the identification of three world-scale deposits (Imfout, Imatra, Imola) in an area of 40 km². The resumption of work in 2006 enabled the discovery of two other shallow
deposits (Imca 25, Imaren), situated 5 km from the previous ones in an area of 1.2 km². The total resources of the Imouraren licence are currently estimated to be 240 000 tU with an average ore grade of 0.08% U of which 70% are classified as measured reserves and are concentrated in the central zone (Imfout) and Imca 25. These reserves are recoverable at an operating cost of less than US $50/lb.

4.3. **Teguida licence**

It is part of the former Abkorun-Azélik exploration licence awarded to the ONAREM-IRSA association in 1974, which discovered several shows and deposits. After the boundaries of this former licence were changed, the central zone where several shows and deposits had been found was named Téguida. It was awarded in 2006 to a group of Chinese companies (SINO-U, ZXJOY INVEST, TRENDFIELD HOLDINGS). The Azélik mining licence (220 km²) was granted to SOMINA in 2008 to exploit the Azélik and Irhawenzeghirhan deposits with economic reserves of 14 000 tU having an average ore grade of 0.2% U.

The Azélik and Irhawenzeghirhan uranium deposits appear in the Lower Cretaceous Assauas formation situated at the base of the Dabla series. Assauas, a Cretaceous formation forms the base of Irhazer; it is composed of very fine sandstone, grey-brown siltite and brownish silty argillites. The mineralized formation lies in erosional unconformity on the light brown clays at the base of the Permian Izégouandane group or the Jurassic Agadez sandstones. The mineralized body is generally tabular with an average thickness of 2 m.

The Azélik deposit is subdivided into several mineralized bodies which start at the surface and sink gently to a depth of 150 m; the Irhawenzeghirhan deposit, on the other hand, is situated around 10 km further north and is 200-210 m deep. The mineralization is basically composed of secondary uranium minerals (tyuyamunite, carnotite). Primary minerals are virtually non-existent. The uranium minerals appear in the form of yellow products in the sandstone and conglomerate matrix of the lower Irhazer unit. Two deposits with measured reserves (RAR) of 14 000 tU, recoverable at an operating cost of less than US $35/lb have been discovered:

- **Irhawenzeghirhan**: 6 000 tU (0.20% U). This deposit is in a tabular layer dipping gently, 0.5 to 3 m thick, in sandstones and polygenetic conglomerates (pebbles of quartz, rhyolite, quartzite, clay);
- **Azélik (TGT)** 8 000 tU (0.24% U).

In the exploration licence and even inside PEX there are good chances of discovering other resources, especially north of the IR deposit and the Teyndi region: complementary, supplementary and geological resources would be of the order of 15 000 tU, bringing the total resources of the SOMINA mining area to close to 30 000 tU.

4.4. **Madaouela licence**

The activities carried out by the CEA in the 1960s led to the discovery of proven reserves of an estimated 6 300 tU (0.36% U) or 9 000 tU with an average ore grade of 0.2% U and an average thickness of 3 m. They are located at a depth of 25 to 70 m at the base of the Guézouman sandstones. While waiting for the results of the exploration activities and confirmation of this high potential licence, the complementary, supplementary and geological resources can be estimated at 21 000 tU, around the numerous mineralized impacts in various sectors.

4.5. **Other licences**

Regarding the other licences, security conditions have not allowed much progress as regards exploration activity; the gradual restoration of peace to the northern region of Niger will lead to acceleration of such activity for the following licences: Terzémazour, Toulouk, Tagait, Adrar Imoles,
Agebout, Afouday, Abelajouad, Assamaka which cover an area of 15 000 km², the geological resources can be conservatively estimated at between 60 000 and 150 000 tU, taking into account the geological models of the known deposits and the experience of Areva NC in the region.

FIG. 6. Mining cadastral survey of the Tim Mersoï Basin uraniferous province.
5. Potential

In addition to the deposits that are already being exploited or being prepared for exploitation, there are good chances of discovering others for the following reasons:

- The existence of several surface shows (Takardaît, Tinégourane, Toulouk, Terzemazour, Moradi, central and eastern Djado, etc.);

- General knowledge of known mineralized impacts (200 and 1 600 m) with interesting potential in the main and most favourable geological area, namely the Tim Mersoï basin (straddling zone on the Arlit-In Azaoua flexure fault);

- The numerous uranium anomalies of Aïr, Djado and Tafassasset (Emi Lulu region) where Pan Ocean has identified surface and shallow shows;

- The spectrometric survey of the Aïr basement showing numerous extended zones with pronounced radioactive anomalies which are worth exploring for primary uranium deposits; many primary uranium vein ore deposits have been discovered in the Hoggar basement in Algeria.

In zones near the Arlit lineament and its satellites where there has not been much previous activity, the resumption of exploration as of 2002 using new methods could lead to other uranium deposit discoveries around the many existing mineralized impacts under the following exploration licences: Imouraren, Madaouela, Adrar Imoles, Afasto, Abelajoud, Agelal, Zéline, Tin Négourane, Téguida, Irhazer, Terzemazour, Toulouk, Tagait, Assamaka and In Gall.

Also, on the down dip of the Arlit, Akouta, Madaouela and Ebba deposits there are other shows and deposits at depths of 300 to 1 500 m in the zone to the west and south-west of the Arlit-In Azaoua flexure. The potential of these highly promising zones in the Tim Mersoï basin varies from 14 to 700 tU/km$^2$. Recent activity under the following licences has led to significant discoveries that have not yet been made fully public.

5.1. In Gall licence

Under this licence, located in the southern part of the Tim Bersoï basin to the south-east of the town of In Gall, inferred reserves estimated at 10 000 tU [7], with an average ore grade of 0.02% U, were discovered by Niger Uranium in 2008. The mineralization is of the unconformity type: it is in a continuous 0.5 to 2.5 m level at the base of Tégama in the erosive contact zone with Irhazer. Like the Teguida N’Tessoum deposit, the In Gall deposit is situated in Cretaceous continental formations. The geological environment is marked by a sandstone and clay alternation.

5.2. Agelal licence

The Agelal licence adjoins the Arlit concession held by AREVA NC and was part of the former Afasto licence operated by Cogema in the framework of an association between OURD and ONAREM at the end of the 1970s. Deep mineralized impacts (500-900 m), with thicknesses of 8 m have been intercepted in the Guézouman sandstones, host to the Akouta, Akola, Afasto and Madaouela deposits. Also, a resumption of exploration by Uranium International Ltd, a Canadian company, has helped to locate shallow resources, suitable for open cast mining, in the Tarat-Madaouela formation (host of the Arlit deposit).

5.3. Adrar Emolès licence

Deep (300 to 500 m) shows of uraniumiferous mineralizations have been intercepted by PNC in Guézouman, Tarat, in the Solomi region.
5.4. **Aïr crystalline massif**

Uranium shows and aero-spectrometric anomalies have been identified in the Aïr massif which, like the Algerian Hoggar, could contain primary mineralisation of uranium.

6. **Total uranium resources**

At the current state of knowledge, the estimated total uranium resources in Niger, based on data provided by the Ministry for Mines, by the mining companies, and extrapolation of geological models of the known deposits in the Tim Mersoï basin, are 500 000 tU of which 140 000 tU are classified as RAR measured resources recoverable at a total operating cost of between US $35–50/lb. The breakdown of the various mining areas is as follows:

- **IMOURAREN SA (Imouraren+ Imca 25):** 240 000 tU (RAR : 55 000 tU)
- **SOMAÏR (Arlit):** 70 000 tU (RAR : 25 000 tU)
- **COMINAK (Akouta +Akola + Ebba):** 65 000 tU (RAR : 26 000 tU)
- **SOMINA (Azelik +IR+Teyndi):** 30 000 tU (RAR : 14 000 tU)
- **MADAOUELA (Mariane +Marylin):** 35 000 tU (RAR : 9 000 tU)
- **IN GALL:** 10 000 tU
- Other less known licences: 50 000 tU

To these resources, additional reserves estimated at around 150 000 tU could be added for the licences currently under development: Madaouela, Anou Agerouf, Afasto, Adrar Emoles, Agelal, Agebout and Téguida.

7. **Conclusion**

Niger has immense uranium resources (500 000 tU, of which 140 000 tU are classified as RAR recoverable at less than US $50/lb) and offers considerable uranium potential, located mainly in the Tim Mersoï basin. Numerous shows and aero-spectrometry anomalies identified in the Aïr massif and two other basins (Tafassasset and Djado) leave room to speculate and hope that the resources that remain to be discovered are even larger. To date, less than 10% of the area of these vast metallogenic provinces, covering 360 000 km$^2$, have been explored in detail.

This optimistic prognosis is based mainly on:

- The existence of a favourable geological environment for uranium entrapment;
- The existence of source rocks for uranium nearby;
- The existence of numerous surface and underground shows;
- A potential of 14–700 tU per km$^2$; and,
- The existence of uranium in solution in aquifers.

**REFERENCES**

Geological setting of the Langer Heinrich uranium deposit, Namibia

E. Becker, K. Kärner
Paladin Energy Ltd, Perth, Western Australia

E-mail address of main author: ed.becker@paladinenergy.com.au

Abstract. The Langer Heinrich Uranium Mine is located in the central Namib Desert, Namibia, some 80km east of the coastal town Swakopmund. Geologically, the Namib Desert lies within the Late Proterozoic Damara orogenic belt consisting of metamorphic sedimentary and volcanic rocks. Different stages of syn- to post-tectonic granites and alaskites have intruded into the Damara rocks, some of them containing naturally high amounts of uranium, e.g. Rössing and Ida Dome alaskites. Rift-related uplift initiated by the break-up of Gondwana in Late Jurassic and related surface denudation of Proterozoic rock units were accompanied by the retreat of the Great Escarpment, which is one of the most prominent morphological features in Namibia and divides e.g. the Namib Desert from the Khomas Hochland plateau. Continuous erosion of the high elevated plateaus and the resulting eastern movement of the Great Escarpment during the Cenozoic led to the deposition of fluvial and alluvial deposits west of the Escarpment. These Cenozoic sediments are host to surficial uranium mineralization throughout the Namib Desert including the Langer Heinrich ore body. The Langer Heinrich ore body occurs over 15 km length and strikes east-west along a palaeo-channel, located between the Langer Heinrich Mountain in the north and the Schieferberge to the south. The host rocks are composed of calcretized conglomerates, grits, and minor sands and silts. The bedding is lenticular with meter-thick fining upward sequences being common. Vertical as well as lateral facies changes are rapid. Carnotite is the only ore mineral and has been precipitated from ground water, with uranium being derived from granites and pegmatites exposed in the vicinity of the Langer Heinrich palaeo-channel. The near-surface mineralisation is between 1m to 30m thick and 50 m to 1 100 m wide depending on the width of the palaeo-valley. At a 250 ppm U₃O₈ cut off grade the current resource comprises 127.1 Mt@0.06% U₃O₈ containing 74 415 t U₃O₈ (164 Mlb U₃O₈) including an ore reserve of 50.6 Mt@0.06% U₃O₈ (65.84 Mlb U₃O₈). Mining operations started in August 2006. The mine has achieved nameplate production in December 2007 and is now in the process of increasing capacity from the original 2.6 Mlb U₃O₈/annum (1 000 tU/annum) to 3.7 Mlb U₃O₈/annum (1 423 tU/annum).

1. Introduction

The Langer Heinrich Uranium Mine (LHU) is located in the west of central Namibia, Southern Africa. It lies in the central Namib Desert, some 80km east of the major deepwater port at Walvis Bay and the coastal town of Swakopmund (Fig. 1).

LHU was the first conventional mining and processing operation to be brought into production in over a decade. Paladin was able to deliver the project on schedule and within the original budget of US $92M despite the significant cost pressures experienced by the mining industry during the twenty month construction term. The mine is currently in full production and in the process of increasing capacity from the original 2.6 Mlb U₃O₈/annum (1 000 tU/annum) to 3.7 Mlb U₃O₈/annum (1 423 tU/annum).

Following the discovery of the calcrete hosted uranium mineralisation in the early 1970s, Gencor conducted an extensive project evaluation over an 8-year period up until 1980. The study indicated that the project had good potential for development but it was subsequently placed on care and maintenance due to depressed uranium prices.
In 1998 the project was sold to the Australian listed public company, Acclaim Uranium NL ("Acclaim") who also completed a highly favourable Pre-Feasibility Study. However, adverse uranium market conditions and low prices in the late 1990s again curtailed development and Acclaim sold its holding in LHU to Paladin in 2002.

Following the acquisition, Paladin initiated a Bankable Feasibility Study (BFS), which was completed in April 2005. This BFS confirmed that the LHU project could generate highly attractive returns using defined reserves only.

Based on a mill throughput design of 1.5Mtpa of ore, the BFS showed 1 180 tpa U₃O₈ can be produced for the first 11 years at a head feed grade of 0.0875% U₃O₈ and 401tpa U₃O₈ over the last 4 years, using the accumulated low grade stockpile grading 0.032%U₃O₈.

**FIG. 1. Location map.**
Site works began in September 2005 and the construction and staged commissioning of the Langer Heinrich Uranium Project (LHU) was successfully achieved on 28 December 2006.

The mine was officially opened by the President of Namibia on the 14th March 2007 and the first commercial product shipment occurred in the same month. The operation achieved nameplate production in December 2007. Work is now nearing completion on the Stage II expansion, which will lift production to 3.7 Mlb (1,423 tU).

2. Regional geological setting

The Langer Heinrich Uranium Mine occurs within the Central Zone of the Damara orogenic belt, which is part of the Neoproterozoic system of Pan-African mobile belts. In Namibia, the Damara Orogen has been divided into a N–S trending coastal branch (Kaoko and Gariep belts) and a NE trending inland branch (Damara belt), which has been interpreted as a result of the collision between the Congo, Kalahari and Rio de la Plata cratons [1][2]. The inland branch has been divided into a number of zones [3] based on lithostratigraphical, structural and metamorphic criteria. The Central Zone of the Damara orogenic belt contains a variety of syn- and post tectonic granites, some of them being uraniferous (e.g. [4][5]. The uraniferous granites, e.g. at Rössing, Valencia, Ida Dome, and Goanikontes are also referred to as sheeted leucogranites and alaskites [4].

The Late Proterozoic Pan-African orogeny was followed by a long period of tectonic stability. The break-up of Gondwana and thus the opening of the South Atlantic Ocean from the south started at about 170 Ma [6] to 130 Ma ago with fully marine conditions established about 80 Ma ago [7]. Rift-related uplift and surface denudation of Proterozoic rock units were accompanied by the retreat of the Great Escarpment, which is one of the most prominent morphological features in Namibia and divides e.g. the Namib Desert from the Khoros Hochland plateau (see Figs 2 & 3). Continuous erosion of the high elevated plateaus and the resulting eastern movement of the Great Escarpment during the Cenozoic led to the deposition of fluvial and alluvial deposits in drainage systems west of the Escarpment, namely sediments of the Namib groups [8]. These Cenozoic sediments are host to surficial uranium mineralization throughout the Namib Desert including the Langer Heinrich ore body [9].
FIG. 2. Generalised map showing the distribution of some major Namib Group deposits and their uranium-bearing zones. Modified after [9].
3. The Langer Heinrich Palaeo-Channel

3.1. Location and morphology

The east-west trending Langer Heinrich palaeo-channel, which hosts the Langer Heinrich uranium ore body, is located in the central Namib Desert. It has eroded into Proterozoic Damara bedrock and is wedged between the Langer Heinrich Mountain in the north and the Schieferberge immediately to the south [10] (see Fig. 4).

The Langer Heinrich palaeo-valley is 50 to 1100 m wide. The incision of the palaeo-channel into the underlying Damara bedrock increases in flow direction. Close to the headwaters at the eastern end of the 15 km long Langer Heinrich mining licence, the palaeo-channel eroded not more than 20 m into the bedrock, whereas downstream at the western end of the mining licence the palaeo-channel eroded up to 100 m deep into the Late Proterozoic bedrock.

The base of the palaeo-channel (river bed) descends from 710 m above sea-level in the east to 510 m above sea level in the west over a distance of 15 km having a gradient of more than 10 m per kilometer. This steep gradient is typical found in the part of a drainage system, which is close to its headwaters. Indeed, the Langer Heinrich palaeo-channel seems to have its origin at the eastern boundary of the Langer Heinrich mining licence.

The incision of the palaeo-channel was superseded by a depositional cycle during which the palaeo-channel was filled with sediments, which subsequently have been calcretized. These sediments are host to the Langer Heinrich ore body.
The present-day Gawib River (see Fig. 4), which mirrors the course of the underlying palaeo-channel to a large extent, has locally eroded parts of calcretized palaeo-channel sediments. As a result, the Langer Heinrich ore body is exposed at the surface in places.

3.2. Local geology

The oldest rocks of the Damara Group comprise quartzites of the Etusis Formation of the Nosib Group, which form the Langer Heinrich Mountain anticlinorium (see Fig. 4). The Schieferberge to the south are composed of a variety of schists and calcisilicates, which are referred to as the Tinkas Formation of the Khomas Subgroup (Swakop Group). Rössing and Khan formations, which are found regionally between the Nosib and Khomas Subgroup are not present in the Langer Heinrich area. Limited outcrop of the diamictites of the Chous Formation occurs west of the Langer Heinrich Mountain (see Fig. 4). Southeast of the Langer Heinrich Mountain, the Bloedkoppie granite, which is a leucocratic late- to post-tectonic Damara granite, has intruded both Nosib and Swakop groups and covers an area of about 25 km² [10]. Additionally, pegmatites are found throughout the Damara sequence. Some of the pegmatites are interpreted as apophyses of the Bloedkoppie granite; others are syntectonic and follow the regional foliation planes [11]. The thickness of pegmatites is highly variable and lies between some decimeters to more than one hundred meters.

FIG. 4. Map showing the distribution of Proterozoic Damara bedrock as well as Cenozoic cover sediments within the Langer Heinrich area. The Gawib River is a present-day drainage system, which mirrors the course of the underlying Langer Heinrich palaeo-channel to a large extent. From [12].

Within the Langer Heinrich area, the east-west trending palaeo-channel traverses through Damara granites in the east, then it is eroded into schists of the Tinkas Formation before its northern bank is formed by the Tinkas/Etusis formations contact. Further downstream, the palaeo-channel eroded into Tinkas Formation again.

The incision of the palaeo-channel was superseded by a depositional cycle during which the palaeo-channel was filled in with fluvial sediments. These fluvial sediments belong to the Langer Heinrich Formation.

Subsequently, alluvial sediments of the Gemsbok Formation were deposited on top of the Langer Heinrich Formation. The two formations are separated from each other by an erosional discontinuity surface.

Deposits, younger than those of the Gemsbok Formation only occur west of the Langer Heinrich Mountain and are summarized as Gawib Flat deposits by several authors (e.g. [11][9]).
3.3. Lithology of Cenozoic host sediments

3.3.1. Langer Heinrich formation

The fluvial Langer Heinrich Formation comprises the oldest Cenozoic sediments that have been deposited along the palaeo-channel. Within the Langer Heinrich area they are up to 90 m thick (see Fig. 5) and calcretized to a large extent.

They are mainly composed of unsorted polymictic conglomerates, grits, and minor sands and silts. Vertical as well as lateral facies changes are rapid.

The bedding is lenticular with meter-thick fining upward sequences being common. Additionally, both trough cross bedding and planar bedding occur in places.

The detrital components consist of subrounded quartz and feldspar granules and pebbles as well as subangular lithofragments deriving from the surrounding country rocks, e.g. schists, calc-silicates, quartzites, and minor granites.

The sediments were cemented by calcite (calcretisation) after their deposition under arid to semi-arid climatic conditions. Calcite cement in sediments of the Langer Heinrich Formation generally displays both sparitic and micro-sparitic cement indicating a ground water origin of the calcrete. This formation is host to the Langer Heinrich ore body. Carnotite, which is the only uranium mineral identified at present, has been precipitated from uranium-bearing groundwaters, with uranium being most likely
derived from surrounding Damara granites and pegmatites and vanadium from the schists of the Tinkas Formation.

3.3.2. Gemsbok formation

The Langer Heinrich Formation is unconformably overlain by the Gemsbok Formation (see Fig. 5), which is only exposed in the central and western portion of the Langer Heinrich mining licence, where it reaches a maximum thickness of 50 m.

These sediments are generally coarse-grained. Detrital components are quartz and feldspar as well as a variety of lithoclasts, but mainly schists and calc-silicates of the Tinkas Formation. The main differences between the Langer Heinrich and the Gemsbok formations are a lack of graded bedding and significantly less vertical and lateral facies changes, which give the Gemsbok Formation an alluvial character.

The Gemsbok Formation is partly calcretized displaying macroscopic and microscopic features that are typical for pedogenic calcretes. This formation does not contain economic uranium mineralisation, although stringers and blobs of carnotite have been locally observed within outcrops of pedogenic calcrete.

3.4. Ore minerals and textures

Uranium mineralisation, which is hosted by the Langer Heinrich Formation, occurs as carnotite, an oxidised uranium and vanadium secondary mineral. The uranium deposit occurs along the Langer Heinrich palaeo-channel over 15 km length in seven higher grade pods (see, Fig. 6) within a lower grade mineralised envelope.

Mineralisation is near surface, 1 m to 30 m thick and is 50 m to 1100 m wide depending on the width of the palaeo-valley.

The ore is classified according to its grain size distribution and carbonate content, e.g. calcareous conglomerates and grits, non-calcareous conglomerates and grit. Carnotite occurs as disseminations within the sediment matrix, as veneers lining cavities and fracture planes, but also as coatings on pebbles and boulders.

The distribution of ore within the palaeo-channel shows that the morphology of bedrock and aquifer controlled the precipitation of carnotite to a certain extent. Narrow portions of the palaeo-channel as well as areas close to bedrock highs commonly contain high grade mineralisation and thus most likely represented ponding situations for ground water with high evaporation rates, which resulted in an increased concentration of uranium and vanadium in solution and therefore precipitation of carnotite.
3.5. **Evolution of the ore body**

The formation of the Langer Heinrich ore body was strongly controlled by the palaeo-morphological and palaeo-climatic evolution of the Namibian continental during the Cenozoic.

Palaeo-climatic conditions that favour the formation of both calcrete and carnitite were given in Eocene/Oligocene as well as in Lower Miocene. However, erosional unconformities within the Langer Heinrich area, which correlate to major geological tectonic events in central Namibia, indicate that the ore body must have formed pre-Miocene (see Table 1 below).
Table 1. Cenozoic evolution of Namibia’s passive continental margin with reference to the Langer Heinrich deposit using [7][13][14][15][8][6][16][17][9][11]

<table>
<thead>
<tr>
<th>Era</th>
<th>Major Geological Events</th>
<th>Palaeo-climate</th>
<th>Tectonics</th>
<th>Langer Heinrich</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary</td>
<td>P-A. II C.</td>
<td>Formation of main Namib sand sea, Incision of the Swakop River</td>
<td>Arid</td>
<td>Sedimentation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pliocene</td>
<td>L.</td>
<td>Establishment Benguela current, formation of pedogenic calcrete</td>
<td>Semi-arid to arid</td>
<td>Stable land surface</td>
</tr>
<tr>
<td></td>
<td>M.</td>
<td>Fluvial sedimentation (Karpfenkliff Formation)</td>
<td>Semi-humid</td>
<td>Sedimentation</td>
</tr>
<tr>
<td>Neogene</td>
<td>Miocene</td>
<td>Proto-Namib desert phase (eolian Tsondab Formation)</td>
<td>Semi-arid/arid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oligocene</td>
<td>Formation of the ‘Namib Unconformity Surface’ (NUS)</td>
<td>Humid to semi-arid</td>
<td>Stable land surface</td>
</tr>
<tr>
<td></td>
<td>Eocene</td>
<td>Post-Gondwana erosional phase</td>
<td>Humid-subtropical</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Palaeocene</td>
<td>Initial break-up of Gondwana</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.6. Resources and reserves

At a 250ppm U₃O₈ cut off grade the current resource contains 32.8 Mt at 0.06% for 19 582 t U₃O₈ in the Measured category, 23.6 Mt at 0.06% for 13 276 t U₃O₈ in the Indicated category and 70.7 Mt at 0.06% for 41 557 t U₃O₈ in the Inferred category. These resources conform to both the JORC (2004) and NI 43-101 guidelines and are quoted inclusive of any ore reserves.
Ore reserve has been announced and reported conforming to both JORC and NI 43-101 guidelines. Based on the current reserve of 50.6 Mt at 0.06% for 29,874 t U₃O₈, the project has a life of a minimum of 17 years, based on increased Stage II production rates.

The resource model is currently being up-dated to take into account further resource definition drilling in 2007 and 2008. It is expected that this exercise will result in a significant increase in resources.

REFERENCES

The geology of the Kayelekera uranium mine, Malawi

E. Becker\textsuperscript{a}, J. Mwenelupembe\textsuperscript{b}, K. Karner\textsuperscript{a}, J.C. Corbin\textsuperscript{a}

\textsuperscript{a}Paladin Energy Ltd, Perth, Western Australia
\textsuperscript{b}Paladin (Africa) Ltd, Lilongwe, Malawi

\textit{E-mail address of main author: ed.becker@paladinenergy.com.au}

Abstract. The Kayelekera Uranium Deposit is located in the northern part of Malawi, Southern Africa, 40 kilometres west of the township of Karonga. Paladin Energy Limited, an Australian based company holds an 85% interest in the Kayelekera Project through its wholly owned subsidiary Paladin (Africa) Limited. The other 15% is held by the Republic of Malawi. Kayelekera is a sandstone-hosted uranium deposit of the roll front type. At a 300 ppm cut-off the deposit contains a total resource of 19,500 t of U\textsubscript{3}O\textsubscript{8} with an average grade of 800 ppm. Reserves include 13,500 tonnes at 1,100 ppm. The deposit is hosted by sediments of the Permian Karoo Sequence in the North Rukuru Basin. Uranium mineralization occurs in four principal lenses developed within arkose units called S and T, the combined mudstone arkose Units U+U+W and arkose unit X. The lenses are superimposed vertically along the axis of a shallow northwest trending syncline. A subparallel fault structure cuts the eastern limb of the mineralised syncline. Uranium mineralisation occurs within reduced and oxidized arkose and is redistributed into mudstones along faults. Coffinite has been identified as the main primary uranium bearing mineral with uraninite being present to a lesser degree. Secondary uranium minerals meta-autunite, boltwoodite and minor uranophane occurs in weathered oxidized rocks near surface and along faults. Paladin completed a Bankable Feasibility Study for the Kayelekera Uranium Project including a comprehensive Environmental Impact Assessment in early 2007 and was granted a Mining Lease in April of that year. Construction started in late 2007 and was completed in March 2009. Ramp up to nameplate production of 3.3 million lbs U\textsubscript{3}O\textsubscript{8} (1,269 tU) from 1.5 million tonnes of ore is currently in progress.

1. Introduction

The Kayelekera Project is located in northern Malawi, 52 km west of the provincial town of Karonga at the northern end of Lake Malawi, and 575 km by road north of the capital city, Lilongwe (see Fig. 1).

Kayelekera is a sandstone-hosted uranium deposit with a resource of 19,900 tonnes of U\textsubscript{3}O\textsubscript{8} at a grade of 0.08% using a 0.03% cut-off. The deposit lies within Permian Karoo sandstones in the northern part of the North Rukuru Basin of Malawi.

The Kayelekera uranium deposit was the subject of detailed evaluation in the 1980s by the Central Electricity Generating Board of the United Kingdom (“CEGB”). Their work culminated in the execution of a full feasibility study in 1991, assessing the viability of constructing and operating a conventional open pit mine and supporting infrastructure. Using the engineering and financial parameters adopted by CEGB, the study indicated that the project was uneconomic at that time. CEGB relinquished its tenure in 1992.

Paladin (Africa) Limited, a wholly owned subsidiary of Paladin Energy Ltd, acquired a 90% interest in the Kayelekera Project in early 1998 and increased its equity to 100% in 2005. Shortly after Paladin’s entry into the project the uranium price weakened and remained low until mid 2003, stalling progress towards development. Subsequent to the turnaround in the uranium market Paladin started active work on the project in 2004.
In 2005 Paladin started a Bankable Feasibility Study (BFS) including a detailed resource drilling programme and announced a new resource to JORC standard in 2006. After completing a Development Agreement with the Malawi Government and the BFS together with a full Environmental Impact Assessment in January 2007, the Mining License, ML152, covering 5,550 hectares was granted in April 2007 for a period of fifteen years. Construction started in June 2007 at a budgeted cost of US$ 200M.
The construction project workforce peaked at around 2,000 persons, with more than 75% of workers being Malawian nationals.

Open pit mining commenced in June 2008 to develop initial stockpiles, with the first blast occurring on 24 July 2008. A grade control drilling programme of approximately 13,000 m was undertaken to define reserves for the first 18 months of mining and results to date show a strong correlation to the updated resource model that was used in the BFS.

Commissioning began in January 2009 with first production achieved mid-April. Production ramp-up is scheduled over the 2009 calendar year, with full design operation targeted for December 2009.

The mine was officially opened on 17 April 2009 by the President of Malawi, Dr. Bingu wa Mutharika.

The project is designed to give an annual production of 3.3 Mlb U₃O₈ (1269 tU) from the processing of 1.5 million tonnes per annum (Mtpa) of sandstone and associated ores by grinding, acid leaching, resin-in-pulp extraction, precipitation and drying to produce saleable product.

2. Access, climate, infrastructure and physiography

The existing access to the Kayelekera project area is via the Karonga - Chitipa road, a journey of about 50 km. The road is un-surfaced for most of its length and allows good access in the dry season but only limited access to vehicles with 4WD and high clearance during the wet season. Construction of an all weather road is currently in progress. Access from the Chitipa road to the project site is via an all weather dirt road constructed by the company in 2008. The nearest airfield is at Karonga. From Karonga, access south is good and the main roads are in excellent condition.

Malawi is a land locked country, and as a consequence all access for imported materials and equipment is either by road through South Africa or via Dar-es-Salaam in Tanzania.

The Kayelekera Project is situated about 10° south of the equator and so has a tropical climate. There are three recognizable seasons during the year established by both rainfall and temperature. A wet season that lasts between mid-November to April, a cool season from May to early August and a hot dry season from August to November (Table 1).

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Chitipa</th>
<th>Karonga</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>29°(Oct)</td>
<td>33°(Oct/Nov)</td>
</tr>
<tr>
<td>Minimum</td>
<td>13°(June)</td>
<td>17°(Jul/Aug)</td>
</tr>
<tr>
<td>Mean Annual</td>
<td>20°</td>
<td>25°</td>
</tr>
<tr>
<td>Annual</td>
<td>1,039mm</td>
<td>1,165mm</td>
</tr>
<tr>
<td>Monthly Max</td>
<td>210mm (Jan &amp; Feb)</td>
<td>335mm (Mar)</td>
</tr>
</tbody>
</table>

In Kayelekera the annual rainfall is about 1,000mm, with a minimum and maximum of 700 mm and 1,600 mm, respectively. Most rain falls between January and March in a limited number of high intensity tropical storms.

Prevailing winds are generally from the SE and are strongest during March to October.

Local population density is low with only a small number of settlements within the vicinity of the project site.
The project site is located in hilly country at the northern end of Lake Malawi. Topography comprises steep and rolling hills separated by winding river valleys. The ground surface varies between 750 m to 1200 m in elevation.

The major river in the area is the North Rukuru River, which flows year round from South to North along the eastern side of the property. There are two tributaries of the North Rukuru River, the Sere and the Muswanga Rivers, with permanent flow. Other streams have only seasonal flows.

Regional vegetation consists principally of light deciduous forest with a variety of small shrubs, herbs and grasses (known as Miombo woodland), with some small, seasonally waterlogged, grass covered depressions (known as Dambos). River fringes are more heavily vegetated with woody species, ferns and bamboos.

Areas of cultivation occur principally around the small settlements and along the banks of the Sere River.

The project area supports a moderately diverse fauna typical of less densely populated areas of Northern Malawi. No species recorded appear on lists of threatened or endangered species prepared by the International Union for the Conservation of Nature.

3. Regional geology

The Karonga area is mainly underlain by metamorphic and igneous rocks of the pre-Karoo Malawi Basement Complex (see Fig. 2). These are overlain by several small basins of Karoo sediments and, nearer to Lake Malawi, Cretaceous to Recent lacustrine sediments. The major lithological components of the basement are gneisses and intrusives of the Misuku Belt, the south-eastern extension of the Ubendian Mobile Belt of south-western Tanzania into Malawi.

The whole area was subjected to four episodes of mainly brittle deformation in the late Precambrian and early Palaeozoic (1200 – 1100 my; 670, 570, and 450 my).

A long period of erosion of the Misuku Belt was interrupted in early Permian by the deposition of Karoo sediments upon a subdued but irregular topography initially under glacial and periglacial conditions. The Karoo sediments occupied several partially or totally fault bounded basins (half graben structures, but in mid-Karoo times probably covered most of the area. The Karoo sequence mainly comprises gritty arkosic sandstones and shales with thin coal seams near the base of the sequence overlain by calcareous mudstones and limestones. Faulting and subsidence accompanied Karoo sedimentation, which ended with the initiation of the Gondwana erosion cycle in Lower Jurassic.

In Upper Jurassic early rift faulting established a depositional basin in the vicinity of what is now northern Lake Malawi. From the Upper Jurassic to the present day a sequence of uplift, erosion and faulting resulted in periodic lacustrine sedimentation, of which relics are preserved in the Rift Scarp Zone and the Lakeshore Plain. The earliest of these lacustrine sediments are sandstones, shales and marls of the Dinosaur Beds of Upper Jurassic or Lower Cretaceous age. Overlying these and separated by successive unconformities are Tertiary conglomerates and sandstones. These are overlain by limestones, marls, sandstones and conglomerates, pebble beds as well as poorly consolidated sands and muddy sands of Pleistocene age. Early Pleistocene Songwe Tuff beds related to an explosive phase of the Rungwe Volcanic Centre in southwest Tanzania are found in a limited area along the Songwe valley. Recent pebble beds, the Dwangwa Gravels, and lacustrine sands and gravels of the Lakeshore Plain mark the retreat of Lake Malawi to its present position.
FIG. 2 Geology of Northern Malawi.
3.1. The geology of the North Rukuru Basin

The Kayelekera uranium mineralization is located close to the north tip of the North Rukuru Basin. The North Rukuru Basin is some 50 km along strike (north - south) and has a maximum width of about 6.5 km. It contains a thick (at least 1 500 m) sequence of Karoo sediments preserved in a half graben about 35 km to the west of and broadly parallel to the Lake Malawi section of the East African Rift System. The faulted eastern margin of the basin probably has been active during sedimentation as some evidence of growth faulting in the Kayelekera open pit shows. To the west, the Karoo sediments rest unconformably on basement gneisses. Figure 3 shows the geology of the northern North Rukuru Basin.

The Karoo sediments at Kayelekera have been divided into three formations, which are from the bottom to the top:

1) Basal Beds (K1)

The Basal Beds, resting unconformably on metamorphic basement rocks, are glacial, fluvioglacial and glacio-lacustrine sediments consisting of diamictites, varved shales and calcareous sandstones.

2) Coal Measures (K2)

Coal measures, sometimes absent, overlie the Basal Beds and consist of discontinuous coal seams, carbonaceous shales and fine grained sandstones.

3) North Rukuru Sandstone and Shale Formation (K3+4)

The lower part of this formation is a thick arkose unit (Kalopa Member), which is overlain by the Muswanga (Red Bed) Member consisting of fining upward cycles of sheet like coarse grained arkoses, red-brown calcareous mudstones and grey to black carbonaceous silty mudstones. The lower arkose of the Muswanga Member is characterised by a primary oxide (hematitic) matrix, partially altered to goethite/limonite on weathering. This unit is overlain by a distinct fossiliferous bed containing silicified wood, which is thought to be the top of K3.

The overlying Kayelekera Member contains the top 150 metres of the North Rukuru Sandstone and Shale Formation and hosts the uranium mineralization at Kayelekera. The Kayelekera Member is composed of arkoses with a primary reduced (chlorite/pyrite) matrix and abundant carbonaceous debris and is thought to be equivalent of the lower K4.
FIG. 3. Geology of the northern North Rukuru Basin.
4. **Local geology**

4.1. **Lithology of the host sediments (Kayelekera Member)**

The Kayelekera deposit lies within the uppermost 150 metres of the North Rukuru Sandstone and Shale Formation (Kayelekera Member). Surface mapping and drill hole information indicate a total of eight separate arkose units with intervening silty mudstones and mudstones in an approximate 1:1 ratio. The detailed lithology of the Kayelekera Member is given in Figs 4 and 5 shows the simplified geological features around the Kayelekera deposit.

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Arkose Code</th>
<th>Average Thickness (m)</th>
</tr>
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<tbody>
<tr>
<td>ARKOSE</td>
<td>R</td>
<td>&gt;12.0</td>
</tr>
<tr>
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<td>SANDSTONE</td>
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<td>COALY SHALE</td>
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</tr>
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</tr>
<tr>
<td>ARKOSE</td>
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<tr>
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<td></td>
</tr>
<tr>
<td>CHOCOLATE MUDSTONE</td>
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</tr>
<tr>
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<td>U</td>
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<tr>
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<tr>
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<tr>
<td>CHOCOLATE SILTY MUDSTONE</td>
<td></td>
<td>&gt;70.0</td>
</tr>
</tbody>
</table>

![FIG. 4. Stratigraphic section.](image)
The succession is indicative of cyclic sedimentation within a broad, shallow, intermittently subsiding basin. Each cyclothem generally passes upwards from coarse grained reduced facies arkose through oxide-facies ‘red bed’ mudstone into reduced facies grey-black carbonaceous silty mudstone. Thin coal rich horizons are present within some cyclothems.
4.1.1. Arkose

The arkose units, which contain uranium mineralization, are on average about 8 metres thick and are generally coarse grained and poorly sorted with a high percentage of fresh pink feldspar clasts. In reduced intersections, seen in core, pink feldspars contrast strongly with the dark-green pyritic, carbonaceous matrix. Individual units may show several fining upward sequences with quartz and feldspar bearing pebbly conglomerate grading into medium or more rarely, fine grained, micaceous arkosic sandstone. Thin mudstone layers may mark the boundary between fining-up units within the arkoses.

Carbonaceous debris as layers on cross-stratification surfaces, disseminations, and as individual ‘woody’ fragments of several centimeters in length are commonly present in association with pyrite within reduced facies arkose intersections. Larger fragments of carbonaceous debris are also found within altered oxidized arkose intersections.

The arkose units are of variable thickness, though they generally thicken towards the northwest, whereas mudstones are thinning or cut out altogether in this direction, indicating that a possible channel system was draining towards northwest.

4.1.2. Chocolate-brown ‘Red Bed’ mudstone

This lithofacies compromises red to chocolate-brown, homogeneous, fine grained sediments with no discernible bedding. Pale green patchy ‘reduction zones’ may be present and in the lower units calcareous, concretionary nodules and calcite veining are common.

4.1.3. Grey carbonaceous silty mudstone

This unit is much more variable then the preceding red beds and comprises a range of lithotypes including:

a) light to dark grey homogeneous mudstones,

b) grey silty mudstones containing discrete quartz grains,

c) silty mudstones containing multi-coloured angular mud clasts;

 d) laminated bedded, carbonaceous, pyritic black shales;

e) fine grained; current bedded, carbonaceous sandstone and ‘coal’ shales.

4.2. Structure of the ore body

The Kayelekera Member of the North Rukuru Sandstone and Shale Formation is folded into gentle synclinal structures by drag against the eastern boundary fault (see Figs 3, 5).

The deposit occupies one of the synclinal structures, which is a down-faulted block bounded by normal faults trending NNW. The eastern margin of the deposit is marked by a major fault zone with similar trend and having a throw in excess of 100 metres.

Transverse faults with limited offset cut across the synclinal structure at Kayelekera causing a dip reversal to the north creating a basin structure bounded by faults on three sides.
5. Uranium mineralization

Four principal mineralized lenses, developed within arkose units ‘S’ and ‘T’, the combined arkose-mudstone units ‘U+V+W’ and arkose units X1-X3 are present within the deposit to a depth of 100 metres from surface [1-2]. Figure 6 shows a cross section through the deposit.

The lenses are superimposed vertically along an axis approximately parallel to the synclinal axis of the fault bounded structure. The mineralization is offset but not confined by the fault structures and potential for extensions of the mineralisation is restricted by outcrop limitations of the hosting lithologies. The mineralization occurs between 0 (outcropping) to 100 metres depth.

Primary mineralization, present within the reduced facies pyritic arkose, is intimately associated with matrix disseminations as well as larger fragments of carbonaceous debris. Coffinite has been positively identified as the principal uranium bearing mineral and occurs together with minor uraninite. An U-Ti mineral, possibly betaite or tanteuxenite, has also been noted.

Near surface weathering of primary (reduced) ore has produced a zone of oxide ore characterised by yellow and green secondary uranium minerals. These have been identified as meta-autunite and boltwoodite. Minor uranophane is also present. Local leaching and redeposition has repeatedly occurred leading to concentration of secondary uranium species in the basal part of the arkoses and in the top of the underlying mudstones.

The mineralizing process appears to be of the geochemical cell type, with cells migrating down dip from the west and southwest. Drill holes in these directions often intersect the ‘tails’ at the upper and lower surfaces of the oxidised arkose characteristic of the passage of an oxidizing front.
6. Ore types

The ore has been classified into four types based on visual identification of the oxidation-reduction state of the hosting lithology [1-2]. These are:

1) Reduced arkose ore
2) Oxidised arkose ore
3) Transitional arkose ore (mixed oxidised – reduced ore)
4) Mudstone ore

Approximately 50% of the total ore is hosted by reduced arkoses, 30% by oxidised arkoses, 10% by transitional arkoses and 10% by mudstone.

Reduced arkose ore within the arkose units contains fresh feldspars and carbonaceous debris with pyrite and chlorite in the matrix. The principal uranium mineral is coffinite with minor uraninite. An U-Ti mineral, possibly betafite or tanteuxenite, has also been noted. Reduced ore is most prevalent in the lower arkose units of the deposit.

Oxidised arkose ore is characterized by feldspar deterioration and the prevalence of iron oxide in the matrix. Near surface weathering of primary (reduced) ore has produced a zone of oxide ore characterized by yellow and green secondary uranium minerals. In general, the oxidized arkoses appear more red or orange-brown than their reduced counterparts and are easily distinguished visually. The uranium mineralization is predominately secondary, with the principal minerals being meta-autunite (bright green) and boltwoodite (yellow). Most of the oxidized ore is found at or near the surface and in zones closer to the periphery of the deposit.

Transitional arkose ore is mixed ore that exhibits varying degrees of oxidation.

Mudstone ore is a reduced ore and contains mainly coffinite with some uraninite in a matrix of clay minerals. It is concentrated along the arkose/mudstone boundary and close to or within faults zones.

The detrital components are mainly feldspar and quartz. The matrix is composed of iron minerals (hematite, pyrite) with minor amounts of carbonaceous debris and calcite. Mineralogical and textural features noted at Kayelekera are common for sandstone type uranium mineralisation. Uranium could have been derived from either intra- or extra-formational sources. Amongst others it was postulated that uranium was most likely emplaced originally in carbonaceous-rich zones as low grade protore. Then, following rift faulting and associated folding, uranium was mobilized in ground water and re-deposited as ore grade concentrations in trap situations.

7. Resources and reserves

Resource definition drilling to accurately define the limits of the ore body and upgrade the resources to indicated and measured categories, comprising 5 433m in 120 holes in 2005 and 9 955m in 132 holes in 2007, resulted in an upgraded resource and reserve estimation. Details are given in Table 2 & 3 below.

Mineral resource estimates conforming to both JORC (2004) and NI 43-101 codes, are as follows:
Table 2. At 300 ppm U₃O₈ cut-off

<table>
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<tr>
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<th>Mt</th>
<th>Grade ppm U₃O₈</th>
<th>Tonnes U₃O₈</th>
<th>Mlb U₃O₈</th>
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<td>Measured Resources</td>
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<td>18.78</td>
<td>725</td>
<td>13,616</td>
<td>30.0</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>22.20</strong></td>
<td><strong>800</strong></td>
<td><strong>17,757</strong></td>
<td><strong>39.1</strong></td>
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<tr>
<td>Inferred Resources</td>
<td>3.9</td>
<td>552</td>
<td>2,152</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Table 3. At 600 ppm U₃O₈ cut-off

<table>
<thead>
<tr>
<th></th>
<th>Mt</th>
<th>Grade ppm U₃O₈</th>
<th>Tonnes U₃O₈</th>
<th>Mlb U₃O₈</th>
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</thead>
<tbody>
<tr>
<td>Measured Resources</td>
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<td>1,612</td>
<td>3,643</td>
<td>8.0</td>
</tr>
<tr>
<td>Indicated Resources</td>
<td>8.13</td>
<td>1,121</td>
<td>9,114</td>
<td>20.1</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>10.39</strong></td>
<td><strong>1,227</strong></td>
<td><strong>12,756</strong></td>
<td><strong>28.1</strong></td>
</tr>
<tr>
<td>Inferred Resources</td>
<td>1.0</td>
<td>945</td>
<td>945</td>
<td>2.1</td>
</tr>
</tbody>
</table>

The Ore reserve estimate, conforming to both the JORC (2004) and NI 43-101 codes, is as follows:

Table 4. At 400 ppm U₃O₈ cut-off

<table>
<thead>
<tr>
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<th>Tonnes U₃O₈</th>
<th>Mlb U₃O₈</th>
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<tr>
<td>Proved Reserve</td>
<td>2.87</td>
<td>1,373</td>
<td>3,943</td>
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<tr>
<td>Probable Reserve</td>
<td>9.75</td>
<td>959</td>
<td>9,342</td>
<td>20.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>12.62</strong></td>
<td><strong>1,053</strong></td>
<td><strong>13,285</strong></td>
<td><strong>29.3</strong></td>
</tr>
</tbody>
</table>

Economic studies undertaken on the current reserve have indicated a mine life of 9 years and a total project life of between 12 and 13 years, following life of mine scheduling studies and the processing of marginal ores at the end of the mine life.

REFERENCES

Abstract. Over 90 percent of the uranium deposits including the most important granite type deposits, volcanic and caldera-related deposits and sandstone type deposits in China have been discovered in Mesozoic-Cenozoic Era. Spatially, there are five uranium metallogenic provinces dominated by South China uranium metallogenic province in South-East China and Tianshan uranium metallogenic province in North-West China.

The granite type deposits are mainly located in South China uranium province with the mineralization ages of 100 Ma – 165 Ma and 47 Ma – 87 Ma respectively. Current studies indicate that uranium deposits with the mineralization ages of 100 Ma – 165 M are normally characterized by relatively high temperature mineral assemblages such as uraninite associated with scheelite and tourmaline. These have been considered as the early stage uranium mineralization in South China, which is the main exploration target currently in South China. Uranium deposits characterized by quartz-pitchblende veins in host granites with the ages of 47 Ma – 87 Ma are the typical granite type uranium deposits in South China, e.g., Xiazhuang uranium ore field. The host rocks are previously considered as the intrusive granites of Yanshan epoch. However, new isotopic dating results show that most granite hosting both early or late stage uranium deposits in South China are the intrusive rocks of Indo-Chinese epoch with the age of granites more than 200Ma.

Xiangshan is the biggest uranium ore field dominated by volcanic and caldera-related deposits in South China uranium metallogenic province. Two stages of uranium mineralization have been identified including the early alkaline hydrothermal mineralization of $115.2 \pm 0.5$ Ma and the late acid hydrothermal mineralization of $99.0 \pm 6.0$ Ma. The host rocks include rhyodacite and porphyroclastic lava dated of 131 Ma to 158 Ma.

Sandstone type uranium deposits are mainly distributed in Tianshan uranium metallogenic province, such as the deposits in Yili Basin, and in the new exploration areas of Erdos Basin and Er’lian basin. Although there are many publications about the mineralization ages of sandstone type uranium deposits which cover a wide range of ages from 8Ma to 120Ma, it is necessary to understand the main mineralization ages by up-to-date isotopic method.

Since large scale mineralization of nonferrous metal, precious metal and rare metal also took place in Mesozoic-Cenozoic Era, uranium deposits have been regarded as one of the mineral resources of minerogenetic series closely related to the tectonic - magmatic evolution in Mesozoic-Cenozoic Era in the mainland of China.

1. General spatial distribution of uranium deposits in China

Over 50 years history of uranium exploration in China have revealed that the spatial distribution of uranium deposits could be limited to three metallogenic domains of Paleo-Asian, Marginal-Pacific and Tethyan, which includes five uranium provinces and eighteen uranium metallogenic regions/belts in the mainland of China [1] (Fig. 1). There are fourteen uranium metallogenic regions/belts located in Marginal-Pacific domain. The uranium deposits in Mesozoic-Cenozoic era, such as the typical granite type, volcanic type and sandstone uranium deposits, are mainly located in Ganhang, Taoshan-Zhuguang and North Tianshan uranium metallogenic regions/belts. With the new discoveries of large
scale sandstone type uranium deposits, North Erdos Basin region is the focus of the current uranium explorations in China.

FIG.1. Uranium metallogenic regions/belts in China.


2. Uranium mineralization ages

Although the oldest uranium mineralization in China could be traced back to over 1 800 Ma, such as the Lianshanguan deposit in Gongchangling-Bahechuang Metallogenic Belt, over 90 percent of the uranium deposits have been discovered in Mesozoic-Cenozoic Era. Figure 2 illustrates that the granite type and volcanic type uranium deposits formed mainly in the age of 40 Ma to 160 Ma, while the sandstone type uranium deposits formed dominantly in Cenozoic era.
Granite Type:

Granite type uranium deposits in Mesozoic-Cenozoic Era dominantly occur in Taoshan-Zhuguang and Chenzhou-Qinzhou metallogenic belts. Typical granite type uranium deposits in South China are characterized by pitchblende veins in host granites and have the mineralization ages of 47 Ma - 87 Ma in the main mineralization stage. The No. 302 uranium deposit, in Taoshan-Zhuguang Metallogenic Belt, is one of the typical granite type deposit with mineralization age of 72 - 95 Ma. The deposit is spatially controlled by faults, having vertical extensions up to 1 000 (Fig.3). Current studies on this deposit indicate that the ore-forming solutions are characterized by high temperature (over 300℃) and salinity of 8 wt% NaCl during the early mineralization stage.

Volcanic Type:

Volcanic type uranium deposits are mainly located in Ganhang metallogenic belt. The Xiangshan uranium ore field in this belt a typical example. Current exploration have found the new ore bodies hosted in rhyodacite porphyry in Zoujiashan deposit (Fig.4). Two stages of uranium mineralization have been identified, an early alkaline hydrothermal mineralization of about 115 Ma and the late acid hydrothermal mineralization of about 98Ma. Latest single zircon SHRIMP data indicate that the age for porphyroclastic lava in Xiangshan is in the range of 131.2±2.6 Ma to143.4±0.6 Ma with the average age of 133.2 Ma.

Sandstone Type:

Sandstone type uranium deposits are mainly found in Tianshan uranium metallogenic province, such as the deposits in Yili Basin. With the discovery of new large scale sandstone type deposits in North Erdos Basin in the last 10 years, the Erdos Basin and Er’lian basin have become the most important uranium metallogenic regions in North China. The reported mineralization ages of sandstone type uranium deposits in China range from 2 Ma to 120 Ma. Because the complexity of metallogenic process for sandstone type uranium deposit, it is difficult to identify the exact mineralization age for an individual deposit. A typical sandstone type deposit represents different mineralization ages in different position. Two examples of sandstone uranium deposits in Erdos basin and in Er’lian basin respectively have been illustrated in this paper (Figs 5, 6). Normally the mineralization age is much older in the tail of the limbs than the age in the roll front (Fig. 5).
FIG. 3. Geological profile of No. 302 uranium deposits in Taoshan-Zhuguang Metallogenic Belt.
FIG. 4. Geological profile of Zoujiashan deposit in Xiangshan uranium ore field.

FIG. 5. Geological profile of exploration line No. II in Dongsheng deposit.

3. Discussion

Comparison with the typical epithermal vein type uranium deposits hosted in granites in South China, current studies indicate that uranium mineralization underwent an early stage “hyperthermal uranium mineralization” in Taoshan-Zhuguang metallogenic belt, characterized by:

* Controlled by ductile shear zone with the high temperature alkaline alterations

* High temperature mineral assemblages such as uraninite associate with scheelite and tourmaline disseminated in granites (Fig. 7)
batholiths are considered as the important basis for large scale hydrothermal uranium mineralization in similar characteristics as that of Yanshan epoch granite, which are superimposed on the Indo-Chinese for Longhuashan granite and 239±2 Ma for Jiangnan granite [2].

With the development of new dating technologies, such as single zircon U-Pb method, the latest results about the ages of granitoids in Xiazhuang, Zhuguang uranium ore field indicate that most granite batholiths are the intrusive rocks of Indo-Chinese epoch, for example, 232-235 Ma single zircon ages for the Baimianshi granite, 223-227 Ma single zircon ages for Caijiang granite, 236±2 Ma for Longhua shan granite and 239±2 Ma for Jiangnan granite [2]. The Indo-Chinese epoch granite batholiths are considered as the important basis for large scale hydrothermal uranium mineralization in Taoshan-Zhuguang uranium metallogenic belt. Hitherto located granite type uranium deposits have the similar characteristics as that of Yanshan epoch granite, which are superimposed on the Indo-Chinese epoch granites during the mineralization.


* Uranium mineralization spatially related to the small intrusions such as syntectonic granitoids
* The mineralization ages are more than 100 Ma.

Following the studies on this type of mineralization, the “hyperthermia uranium mineralization” is currently considered as the main exploration target with prospect foreground in South China.

FIG. 7. Uraninite associate with scheelite and tourmaline disseminated in granites, Zhushanxia. deposit in Xiazhuang U ore field

The Importance of Indo-Chinese Epoch Granite:

With the development of new dating technologies, such as single zircon U-Pb method, the latest results about the ages of granitoids in Xiazhuang, Zhuguang uranium ore field indicate that most granite batholiths are the intrusive rocks of Indo-Chinese epoch, for example, 232-235 Ma single zircon ages for the Baimianshi granite, 223-227 Ma single zircon ages for Caijiang granite, 236±2 Ma for Longhua shan granite and 239±2 Ma for Jiangnan granite [2]. The Indo-Chinese epoch granite batholiths are considered as the important basis for large scale hydrothermal uranium mineralization in Taoshan-Zhuguang uranium metallogenic belt. Hitherto located granite type uranium deposits have the similar characteristics as that of Yanshan epoch granite, which are superimposed on the Indo-Chinese epoch granites during the mineralization.
The Relations of Uranium Mineralization to tectonic – dynamic environments in Mesozoic-Cenozoic Era:

In addition to uranium, large scale mineralization of nonferrous metal, precious metals and rare metals also took place in Mesozoic-Cenozoic Era in China. Previous studies proved that most of the economic mineral resources discovered in east China (Marginal-Pacific metallogenic domain) are formed during 80 Ma to 180 Ma [3]. The facts imply that these metallogenic systems are closely related to the lithosphere evolution under different tectonic – dynamic environments in Mesozoic-Cenozoic Era in the mainland of China. Therefore, based on the current studies, the relations of uranium mineralization to tectonic-dynamic environment in Mesozoic-Cenozoic era can be briefly described as:

* The early uranium mineralization during 135-157 Ma in Taoshan-Zhuguang uranium metallogenic belt coincided with the lithosphere thickening in a compression environment during Upper Jurassic and Lower Cretaceous periods.

* Late Lower Cretaceous tectonic-dynamic environment switching from the compression to extension took place after 135 Ma in South China. This led to regional lithosphere thinning and promoted the mantle-crust interactions under tensile tectonics. The extensive volcanism and granitoid intrusions in Ganhang and Taoshan-Zhuguang uranium metallogenic belts also took place under such a tectonic-dynamic environment, for example, the granite porphyry or porphyritic granite in Xiangshan uranium ore field with the ages of 131 Ma to 133 Ma and the trachytic-dacite in North Guangdong province with the age about 135 Ma by single zircon SHRIMP dating [4]. The extensive volcanism and granitoid intrusions in tensile tectonic-dynamic environment and the superimposing of late uranium mineralization of the early stage mineralization are considered as the setting for large scale uranium mineralization in South China.

REFERENCES

The latest progress on the study of mineralization genesis in Baimianshi uranium ore field

H.H. Fan\textsuperscript{a}, D.B. He\textsuperscript{a}, F.G. Wang\textsuperscript{a}, D.Z. Gu\textsuperscript{b}, J.R. Lin\textsuperscript{a}, J.S. Rong\textsuperscript{a}

\textsuperscript{a}Beijing Research Institute of Uranium Geology, CNNC, Beijing, China

\textsuperscript{b}Guiyang Research Institute of Geochemistry, Chinese Academy of Science, Guiyang, China

\textit{E-mail address of main author: fhh270@263.net}

Abstract. This paper systematically studies the mineralization related fluid inclusions in fluorite and quartz viz., their shape, composition and homogenisation temperature; contrasts the Sm-Nd, Rb-Sr isotopic characteristics of granite in basement to that of fluorite of ore-forming stage; analysis of the mineralization genesis, typical mineral assemblage and ore-forming age of mineralization in Baimianshi uranium field. The latest research shows that deposits in Baimianshi uranium field are of typical hydrothermal type. The uranium is mainly derived from crustal rocks. A continuous extraction of uranium from the upper crust within granites in the basement by mantle-derived fluids with little of ore-forming elements could have been responsible for the remobilization and transformation of uranium. The mixing of metallogenic elements-rich fluid with groundwater in some draped places overlain by layers of basalt leads to the precipitation of ore-forming materials. Three phases of uranium mineralization exist with ages of 160 Ma, 128 Ma and 103–86 Ma, respectively. The uranium ore deposits in the area formed by a compound metallogeny.

It was formerly believed that deposits in Baimianshi orefield have the same characteristics and genetic types. Syn-sedimentary uranium concentrations and post-diagenetic U-enrichment were responsible for the deposit. The deposit had been considered as sandstone type and volcanic thermal cover subtype on the basis of its genesis. But this paper, taking Huangnihu deposit as an example, points out that Baimianshi orefield is of hydrothermal type. By the study of fluid inclusions, isotopic tracing, mineral assemblages, as well as U-Pb isotopic dating of ores, the metallogenesis has been divided into three stages: the first stage is related to bimodal volcanism; the second stage is related with Yanshanian magmatic activities; and the third stage has a relationship with the diagenesis of sub-volcanic rocks and dikes (quartz porphyry, diabase). The new research results will guide the further prospecting in the deeper parts of this basin.

1. Regional geology

Baimianshi uranium orefield is located in the east of Nanling U-polymetallic ore belt, including Baimianshi, Longkong, Shuangkong, Majitang, and Huangnihu deposits, as well as a lot of ore occurrences such as Zhaixia, Xialanfeng, etc. Geotectonically it is located at the Quannan-Xunwu uplift between Cathaysia and South China fold belts[1].

Strata in this region are mainly Pre-Sinian with minor Mesozoics. Magmatic activities are prominent as seen by Baimianshi, Danguanzhang, and Luofu plutons. During the Mesozoic, volcanism has been evidenced by the bottom cover of Baimianshi basin, which is basalt interbedded with mid-Jurassic sandstone, and rhyolite in the upper part. As a result, bimodal volcanic rocks- basalt, rhyolite and rhyolitic porphyry are seen in this area. Besides, in the orefield, dikes with complex lithology such as diabase, lamprophyre, quartz porphyry and rhyolitic porphyry are very common.
Regional structures are mainly faults due to extensional tectonics. Faults closely related to metallogenesis include Quannan-Xunwu E-W fault belt, NNE Yingtian-Anyuan, Shaowu-Heyuan fault belts and N-W basin-controlling fault. The extensional tectonics is controlled by one or more deep faults, mostly as NE or NNE extensional belts. At the junction between basement E-W tectonic belt and NNE extensional tectonics, thermal-uplifting and down-faulting extensional tectonics [2, 3] have taken place along a EW tectonic belt.

2. Research progress of Baimianshi orefield

2.1. Research on fluid inclusions

Fluid inclusions are the preserved integrated and direct samples of original fluid (or melt) [4, 5]. Study of the composition and mechanism of formation of the fluid inclusions give an understanding of the geologic environment, the genesis and evolution of the deposits.

2.1.1. Types of fluid inclusions

In this paper, fluid inclusions are sampled from the ore-bearing sections of the first layer in Huangnihu uranium deposit, including sandstone, granitic sandstone and basalt. Under microscope, fluid inclusions are primarily epigenetic, mostly located along fissures as linear or group, while a few of them are syngenetic, and occurring like even spots. They are the mainly liquid-gas facies, folowed by liquid facies, and a few are gas facies ones. The ratio of gas to liquid facies is about 20-50. Daughter mineral-bearing tri-facies inclusions are also found, but the daughter minerals are small (<1 µm) and seem to be NaCl crystals. Mostly the inclusions are regular round or ellipse, and usually 3-10µm in size. Some of them are larger than 20µm, with irregular branch or knife shapes. Moreover, inclusions <1µm are also frequent. As a whole, in quartz and siliceous veins, the inclusions are small, few and regular, while in fluorite, they are large, many and mostly irregular.

2.1.2. Homogenisation temperature and salinity of fluid inclusions

Table 1 shows the homogenisation temperature and salinity analysis result of fluid inclusions in Huangnihu deposit. Histogram Fig.1 gives the statistical homogenisation temperature with 10°C as a unit. Histogram Fig. 2 is the statistical salinity taking 0.5 wt % NaCl as a unit. From the histograms we can see that, in Huangnihu deposit, the homogenisation temperature has a large range (70-438°C), with two peaks: low temperature (T1) of 100-170°C and mid-high temperature (T2) of 270-350°C. On another side, the salinity variation includes three ranges: low salinity (S1) of 0.5-1.5 wt % NaCl, middle salinity (S2) of 6-10.5 wt % NaCl and high salinity (S3) of 15.5-16.5 wt % NaCl. It is believed that in most cases the temperature has decreased with geologic age, that is to say, multi-staged fluid activities are indicated by the existence of fluid inclusions with different homogenisation temperatures and salinities [5]. According to the relationship between temperature and salinity (shown in Table 1), fluids in this district can be divided into: low-temperature and low-salinity fluid, mid-low-temperature and low salinity fluid, mid-low-temperature and middle salinity fluid, mid-low-temperature and high salinity fluid, mid-high-temperature and middle salinity fluid, high-temperature and volatile-rich fluid (Figs 1-6).

<table>
<thead>
<tr>
<th>Sn</th>
<th>Mineral</th>
<th>Size (µm)</th>
<th>V/L (%)</th>
<th>Homogenisation Temperature °C</th>
<th>Salinity (wt%NaCl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HN-3</td>
<td>Q</td>
<td>3-8</td>
<td>5-30</td>
<td>70, 73, 77, 83(2), 86(4), 88(2), 90(3), 92, 107, 110(3), 113(4), 117, 121(3), 127, 130(3), 137, 140(5), 147, 151(3), 153, 169, 171, 177, 187</td>
<td>2.57(2), 2.90(2), 2.07(2)</td>
</tr>
<tr>
<td>Sn</td>
<td>Mineral</td>
<td>Size (μm)</td>
<td>V/L (%)</td>
<td>Inclusions of the same stage and the same type</td>
<td>Homogenisation Temperature (°C)</td>
</tr>
<tr>
<td>----</td>
<td>---------</td>
<td>-----------</td>
<td>---------</td>
<td>-----------------------------------------------</td>
<td>-------------------------------</td>
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<td>HN-15</td>
<td>Q</td>
<td>3–6</td>
<td>10–30</td>
<td>143, 147, 167, 178(2), 183, 185, 197, 240, 242, 249, 256</td>
<td>7.17(2), 7.45(2), 8.28(2)</td>
</tr>
<tr>
<td></td>
<td>FL</td>
<td>10–30</td>
<td>0–10</td>
<td>96(2), 100(3), 103(2), 105, 107(2), 110(2), 128, 130, 137, 146, 149</td>
<td>16.40(2), 16.55(2), 16.98(2), 17.12(2)</td>
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<tr>
<td></td>
<td>FL</td>
<td>10–20</td>
<td>10–20</td>
<td>120, 123, 130, 133, 136, 142(2), 144(3), 146(2), 149(3), 157(2), 160, 169, 174(2)</td>
<td>16.55, 16.40, 16.30(2), 14.64(2), 12.16, 12.02</td>
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<tr>
<td>Continuous</td>
<td>Q Vein</td>
<td>6–12</td>
<td>0–20</td>
<td>106, 124, 146, 149(2), 166, 170, 179(2)</td>
<td>7.17(2), 8.59(3), 9.08, 9.21(2)</td>
</tr>
<tr>
<td>HN-2</td>
<td>Q Vein</td>
<td>6–10</td>
<td>30–50</td>
<td>319, 322, 327, 339(2), 342(2), 348(3), 379(3), 383(2)</td>
<td>6.45(2), 6.59(2)</td>
</tr>
<tr>
<td></td>
<td>Q Vein</td>
<td>3–8</td>
<td>20–30</td>
<td>220, 227, 229(2), 322, 327, 330(2), 351, 353(2), 357</td>
<td></td>
</tr>
<tr>
<td>HN-4</td>
<td>Q</td>
<td>8–20</td>
<td>0–5</td>
<td>80(2), 83(2), 87(2), 89(2), 109, 113, 120</td>
<td>1.23(2), 1.74(2)</td>
</tr>
<tr>
<td></td>
<td>Q</td>
<td>5–20</td>
<td>5–10</td>
<td>150, 153(2), 158(2), 160, 167, 169, 173</td>
<td>7.73(2), 7.86, 8.95</td>
</tr>
<tr>
<td></td>
<td>Q</td>
<td>5–20</td>
<td>30–60</td>
<td>370, 373, 377, 380, 385</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Q</td>
<td>5–20</td>
<td>70–80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HN-1</td>
<td>Q</td>
<td>2–20</td>
<td>5–10</td>
<td>151, 153(2), 155, 163, 166, 169(2), 208(2), 210(2)</td>
<td>5.86, 6.16, 7.45(2), 7.73(2)</td>
</tr>
<tr>
<td></td>
<td>Q</td>
<td>2–20</td>
<td>10–20</td>
<td>187, 189(2), 190, 193, 204, 206(2)</td>
<td>1.40(3), 1.74(2)</td>
</tr>
<tr>
<td></td>
<td>Q</td>
<td>2–20</td>
<td>20–30</td>
<td>276, 280, 300, 306, 331, 350</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Q</td>
<td>4–10</td>
<td>30–50</td>
<td>358, 360, 390, 420</td>
<td></td>
</tr>
<tr>
<td>HN-1</td>
<td>Q Vein</td>
<td>3–10</td>
<td>5–10</td>
<td>120, 124(2), 126(3), 130(5), 133, 137(2), 141(2), 147(2), 150(2), 153, 163, 166</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Q Vein</td>
<td>3–6</td>
<td>10–30</td>
<td>170, 177, 179(2), 207, 257, 259, 287, 293(2), 302, 312, 355(2)</td>
<td></td>
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<tr>
<td>Continuous</td>
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</table>

Inclusions of the same stage and the same type: Fluc. 10~20 10~20

Continuous
<table>
<thead>
<tr>
<th>Sn</th>
<th>Mineral</th>
<th>Size (µm)</th>
<th>V/L (%)</th>
<th>Homogenisation Temperature (°C)</th>
<th>Salinity(wt%NaCl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HN-1</td>
<td>FL</td>
<td>4–10</td>
<td>5–20</td>
<td>117, 122(3), 134, 136, 141, 147, 150</td>
<td>5.86, 6.16, 7.45(2), 7.73(2)</td>
</tr>
</tbody>
</table>

*Analysed by F.I. Laboratory, BRIUG with LINKHAM THMS600 based on EJ/T 1105-1999; number in brackets means the times of the same datum.

**FIG.1.** Histograms showing homogenisation temperatures of fluid inclusions in Huangnihu uranium ore-field.

**FIG.2.** Histograms showing salinities of fluid inclusions in Huangnihu uranium ore-field.

### 2.1.3. Composition of fluid inclusions

Because Raman spectra is activated only by covalent bond but not, electrovalent bond [6], the Raman analysis did not give the salinity composition of fluid inclusions. The Laser Raman analytical result of fluid inclusions in Huangnihu deposit (Table 2) shows that the gas-facies of inclusions are composed of H₂, CO₂, CH₄ and H₂O. Besides, liquid-facies of inclusions in siliceous veins in HN-3 basalt contain liquid-facies CO₂, and a weak peak of NO₃⁻ is also found in liquid-facies of inclusions in quartz veins associated with HN-13 pitchblende.

In sandstone, gas-facies of fluid inclusions in fluorite veins are primarily H₂, which is relatively high in some inclusions. In basalt, gas-facies of inclusions in siliceous vein are mainly CO₂ with a little CH₄. In granitic sandstone, gas-facies of inclusions in siliceous veins are mostly CO₂ with traces of
CH₄. Gas-facies of inclusions in quartz veins associated with pitchblende are CO₂, while those in fluorite veins are primarily H₂ with a little CH₄.
The compositions of mantle fluid are known to be mainly CO$_2$ and H$_2$O, minor CO, CH$_4$, H$_2$, N, S, alkali metals and rare gas such as He, Ar, etc. [7][8][9]. However, the fluid from lower mantle or mantle-core boundary, as well as hydrogen circle of outer core contains higher H$_2$, and about 97.8% [10–11] of them are CH$_4$ and H$_2$. Gas-facies of fluid inclusions in this area are rich in CO$_2$, H$_2$ and CH$_4$, indicating part of the fluid is from mantle.

2.1.4. Fluid stages

In most cases, the homogenisation temperatures of fluid inclusions decreases with geologic age [5], so fluids in this district evolved from high temperature to low. According to their shapes, homogenisation temperature, salinity, composition of gas-facies, and corresponding relationship (Tables 1, 2) of the inclusions, fluid in this district is divided into 4 categories (6 sub-categories):

I. High temperature volatile-rich fluid: the homogenisation temperature is higher than 360°C and up to 438°C; the inclusion-hosting mineral is quartz; inclusions are located as spots or groups, with regular round or ellipse shapes; liquid-facies fluid inclusions with high gas-liquid ratio or gas-facies inclusions are mostly syngenetic inclusions in quartz, of which the gas-facies are mainly CO$_2$, with a little CH$_4$, but without H$_2$.

II. Mid-high temperature and middle-salinity fluid: the homogenisation temperature is 270-350°C; the salinity is intermediate (about 6–9wt%NaCl); the inclusion-hosting mineral is quartz; inclusions are located as group or band, with regular ellipse shapes; gas-liquid ratio is mainly 30-50%; the gas-facies are mainly CO$_2$ and CH$_4$, and traces of NO$_3^-$ in liquid-facies.
Table 2. Chemical compositions of Gas in the fluid inclusions in Huangnihu uranium ore-field*

<table>
<thead>
<tr>
<th>Sn</th>
<th>Mineral</th>
<th>Facies</th>
<th>Raman Peak (cm⁻¹)</th>
<th>Raman Intensity</th>
<th>Composition</th>
<th>Characteristic Peaks (cm⁻¹)</th>
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<tbody>
<tr>
<td>HN-1c</td>
<td>Fl</td>
<td>L</td>
<td>3418.76</td>
<td>9241.41</td>
<td>H₂O</td>
<td>3310~3610</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G</td>
<td>4156.73</td>
<td></td>
<td>H₂</td>
<td>4154~4165</td>
</tr>
<tr>
<td></td>
<td>Fl</td>
<td>G</td>
<td>4158.12</td>
<td>9431.29</td>
<td>H₂</td>
<td>4154~4165</td>
</tr>
<tr>
<td>HN-2b</td>
<td>Q</td>
<td>G</td>
<td>1388.47</td>
<td>7287.05</td>
<td>CO₂</td>
<td>1386~1390</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L</td>
<td>3457.68</td>
<td>10857.1</td>
<td>H₂O</td>
<td>3310~3610</td>
</tr>
<tr>
<td>HN-2e</td>
<td>Q</td>
<td>G</td>
<td>2917.63</td>
<td>461.683</td>
<td>CH₄</td>
<td>2913~2919</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G</td>
<td>2915.58</td>
<td>708</td>
<td>CH₄</td>
<td>Validated</td>
</tr>
<tr>
<td>HN-3a</td>
<td>Q</td>
<td>L</td>
<td>2916.19</td>
<td>2187.39</td>
<td>CH₄</td>
<td>2913~2919</td>
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<tr>
<td></td>
<td></td>
<td>G</td>
<td>1384.15</td>
<td>1971.85</td>
<td>CO₂</td>
<td>1382~1386</td>
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<tr>
<td>HN-4a</td>
<td>Q</td>
<td>G</td>
<td>1386.92</td>
<td>7956.77</td>
<td>CO₂</td>
<td>1386~1390</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L</td>
<td>3433.59</td>
<td>3493.47</td>
<td>H₂O</td>
<td>3310~3610</td>
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<tr>
<td>HN-4e</td>
<td>Q</td>
<td>G</td>
<td>2917.06</td>
<td>973.179</td>
<td>CH₄</td>
<td>2913~2919</td>
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<td></td>
<td></td>
<td>G</td>
<td>2915.58</td>
<td>961</td>
<td>CH₄</td>
<td>Validated</td>
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<tr>
<td>HN-13a</td>
<td>Q</td>
<td>G</td>
<td>1386.92</td>
<td>6907.7</td>
<td>CO₂</td>
<td>1386~1390</td>
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<tr>
<td>HN-13c</td>
<td>Q</td>
<td>G</td>
<td>1387.03</td>
<td>6550.49</td>
<td>CO₂</td>
<td>1386~1390</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G</td>
<td>2915.58</td>
<td>1387</td>
<td>CH₄</td>
<td>2913~2919</td>
</tr>
<tr>
<td>HN-13c</td>
<td>Q</td>
<td>L</td>
<td>1046.9</td>
<td>3701.64</td>
<td>NO₃⁻</td>
<td>1040~1060</td>
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<tr>
<td>HN-13</td>
<td>Q</td>
<td>G</td>
<td>1387.03</td>
<td>2722.21</td>
<td>CO₂</td>
<td>1386~1390</td>
</tr>
<tr>
<td>HN-13-1c</td>
<td>Q</td>
<td>G</td>
<td>2918.45</td>
<td>4045.15</td>
<td>CH₄</td>
<td>2913~2919</td>
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<tr>
<td></td>
<td>Fl</td>
<td>G</td>
<td>4158.12</td>
<td>12432.3</td>
<td>H₂</td>
<td>4154~4165</td>
</tr>
</tbody>
</table>

*Analysed by the Institute of Physics, CAS with LABHR-VIS LabRAM HR

III. Mid-low temperature fluid: the homogenisation temperature is 120-180°C; the inclusion-hosting minerals are quartz and fluorite; inclusions are located as group or band, with regular shapes; gas-liquid ratio is mainly 5~30%; the gas-facies are mainly CO₂, CH₄ and H₂; 3 sub-categories can be recognized based on salinity:

III-1. Mid-low temperature and low salinity fluid, of which the salinity is 0.53-1.74wt% NaCl and the hosting mineral is mainly quartz;

III-2. Mid-low temperature and middle salinity fluid, of which the salinity is between III-1 and III-3 (2.07-14.64wt% NaCl) and the hosting minerals are fluorite and quartz;

III-3. Mid-low temperature and high salinity fluid, of which the salinity is 16.30-17.12wt% NaCl and the hosting mineral is mainly fluorite, characterized by the occurrence of H₂ in gas-facies.
IV. Low-temperature and low-salinity fluid: the homogenisation temperature is 80–90°C; the salinity is 1.23-1.74wt% NaCl; the inclusion-hosting mineral is quartz; inclusions are located as band, with irregular shapes; gas-liquid ratio is lower than 10%; the gas-facies are mainly H<sub>2</sub> and CH<sub>4</sub>.

On the whole, fluid salinity in this district varies from low to high; low because the fluid is mixed with other low-salinity fluid, the salinity variation is irregular as fluid is primarily of low-salinity. Genetically, fluid with such an irregularly varying salinity is the result of deep-derived high-temperature high-salinity fluid mixing in different proportion with supergene low-temperature low-salinity fluids.

2.2. Research on isotopes

Rb-Sr isotopes data (Table 3) of metallogenetic purple fluorite in Huangnihu deposit shows that in fluorite the ($^{87}$Rb/$^{86}$Sr)$_i$=0.721895-0.722994, which is characteristic of crust; however, it is lower than ($^{87}$Rb/$^{86}$Sr)$_i$ in Baimianshi basement granite as 0.72462 [1, 2]. $\varepsilon_{Sr}$ value is 250-265, which is also lower than that of granite (292-296). The Sm-Nd isotopes of fluorite (Table 4) are lower compared with basement granite, while the ratio of Sm/Nd is obviously higher. In fluorite, $\varepsilon_{Nd}(t)$ = -12.5856 to -13.7974, and in basement two-mica granite,$\varepsilon_{Nd}(t)$ = -10.4741 to -12.3052. $\varepsilon_{Sr}$ and $\varepsilon_{Nd}$ indicate the metallogenetic fluid is partly composed of paleo-crust, as it is derived from CHUR source area with low Sm/Nd which represents paleo-crust or the addition of paleo-crust. For fluorite, $t_{DM}$=1 971~2 069 Ma, and for granite, $t_{DM}$ = 1 873~2 021 Ma. Both don’t differ very much with each other, and are the result of crust-mantle differentiation of the same stage. Comparison between the fluorite and basement granite shows that the fluid which produced the fluorite was derived from deep granitic magma with source differentiation or directly from CHUR with contamination of many paleo-crust materials on its way up.

Table 3. Rb-Sr isotopic data of fluorite in Huangnihu uranium ore-field

<table>
<thead>
<tr>
<th>Sn</th>
<th>color</th>
<th>Rb($10^{-6}$)</th>
<th>Sr($10^{-6}$)</th>
<th>$^{87}$Rb/$^{86}$Sr</th>
<th>$^{87}$Sr/$^{86}$Sr</th>
<th>t (Ma)</th>
<th>($^{87}$Rb/$^{86}$Sr)$_i$</th>
<th>$\varepsilon_{Sr}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HN-14-1</td>
<td>Colorless</td>
<td>0.4</td>
<td>47.1</td>
<td>0.0245</td>
<td>0.721951</td>
<td>160</td>
<td>0.721895</td>
<td>249.62</td>
</tr>
<tr>
<td>HN-14-2</td>
<td>Purple</td>
<td>0.13</td>
<td>37.5</td>
<td>0.0104</td>
<td>0.723018</td>
<td>160</td>
<td>0.722994</td>
<td>265.22</td>
</tr>
<tr>
<td>HN-12</td>
<td>Purple</td>
<td>0.51</td>
<td>28.2</td>
<td>0.0523</td>
<td>0.722975</td>
<td>160</td>
<td>0.722856</td>
<td>263.26</td>
</tr>
<tr>
<td>HN-1</td>
<td>Purple</td>
<td>1.31</td>
<td>29.1</td>
<td>0.1299</td>
<td>0.723037</td>
<td>160</td>
<td>0.722742</td>
<td>261.63</td>
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</table>

* Analysed by Isotopic Laboratory, BRIUG, based on EJ/T 692-92 with ISOPROBE-T No.7734.

Table 4. Sm-Nd isotopic data of fluorite and basement-granite of in Huangnihu uranium ore-field

<table>
<thead>
<tr>
<th>Sn</th>
<th>color</th>
<th>Sm ($10^{-6}$)</th>
<th>Nd ($10^{-6}$)</th>
<th>$^{147}$Sm/$^{144}$Nd</th>
<th>$^{143}$Nd/$^{144}$Nd</th>
<th>Sm/Nd</th>
<th>T</th>
<th>$\varepsilon_{Nd}(t)$</th>
<th>$t_{DM}$ (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HN-14-1</td>
<td>Colorless</td>
<td>2.58</td>
<td>4.7</td>
<td>0.3314</td>
<td>0.512072</td>
<td>0.57</td>
<td>160</td>
<td>-13.7974</td>
<td>2069</td>
</tr>
<tr>
<td>HN-14-2</td>
<td>Purple</td>
<td>1.39</td>
<td>3.84</td>
<td>0.2193</td>
<td>0.511991</td>
<td>0.37</td>
<td>160</td>
<td>-13.0878</td>
<td>2012</td>
</tr>
<tr>
<td>HN-12</td>
<td>Purple</td>
<td>0.95</td>
<td>2.74</td>
<td>0.2103</td>
<td>0.511952</td>
<td>0.36</td>
<td>160</td>
<td>-13.665</td>
<td>2058</td>
</tr>
<tr>
<td>HN-1</td>
<td>Purple</td>
<td>1.2</td>
<td>3.32</td>
<td>0.2186</td>
<td>0.512016</td>
<td>0.37</td>
<td>160</td>
<td>-12.5856</td>
<td>1971</td>
</tr>
<tr>
<td>B2-1</td>
<td>Basement</td>
<td>7.43</td>
<td>52.38</td>
<td>0.0858</td>
<td>0.511929</td>
<td>0.15</td>
<td>249.9</td>
<td>-10.4741</td>
<td>1873</td>
</tr>
<tr>
<td>B3-11</td>
<td>Granite</td>
<td>7.31</td>
<td>48.13</td>
<td>0.0918</td>
<td>0.511836</td>
<td>0.16</td>
<td>249.9</td>
<td>-12.3052</td>
<td>2021</td>
</tr>
<tr>
<td>HN-9</td>
<td></td>
<td>6.43</td>
<td>37.7</td>
<td>0.1031</td>
<td>0.511873</td>
<td>0.18</td>
<td>249.9</td>
<td>-11.9438</td>
<td>1992</td>
</tr>
</tbody>
</table>

* Analysed by Isotopic Laboratory, BRIUG based on EJ/T 546-91 with ISOPROBE-T No.7734.
2.3. **Indicator minerals**

Five ore mineral groups can be recognized in Baimianshi orefield: U-hematite, U-chlorite, U-sulfide, U-fluorite and U-carbonate types. The primary uranium minerals are uraninite, brannerite, coffinite, etc., and occur as bands, breccia, zoned, vein, disseminated, and concretions. The gangue minerals are galena, hematite, marcassite, sphalerite, etc., occurring in irregular shapes or as veins.

Track etching, radioactive photography and electron microscopy, show that besides brannerite and pitchblende, uranium also occurs in mineral fissures and margins in organic material or in clay cement as discrete particles or as disseminations. (Figs 8 - 13).

Electron microscopic analysis for uranium minerals reveals that brannerite has molar ratio of Ti/U in the range 0.84-2.18, and considering isomorphic Th, Pb, Ca, Mg, Fe and Mn in the calculation, the molar ratio is 0.76-1.85. Therefore, uranium minerals are indicated not to be uniform, and primarily uraninite, brannerite, but also their mixture. These brannerite are not inherited from the diagenesis of basement granite, but from hydrothermal Ti. As the fluids are not mixed homogenously, the content of Ti varies largely, with TiO₂ up to 34.71%.

2.4. **Metallogenetic ages**

U-Pb isotopic dating of pitchblende in ores of the area gives two ages: the early one is 160.4±0.5 Ma, while the late one is 128±0.8 Ma. Previous studies had indicated one more younger age. The first stage of uranium metallogenesis is 160.4±0.5Ma, related to bimodal volcanism (diagenetic age of basalt is 172.8±7.7 Ma, and rhyolite is 164.8±0.57 Ma); the second age is 128±0.8 Ma, related to Yanshanian magmatism (in north of the basin, Danguanzhang rock body and multi-stages of complements); and the third one is 103~86 Ma, related to sub-volcanic rocks and dikes, namely quartz porphyry (99 Ma) and diabase (105 Ma). Furthermore tobernite, autunite, etc., indicate secondary alteration after hydrothermal mineralization.

3. **Conclusions and discussion**

(1) Baimianshi uranium orefield is hydrothermal type. The source of metals is from crust, and the fluid could be partly from mantle. As the fluid migrated up, it extracted metals from crust and basement granite, then deposited them in favorable area in the upper levels.

(2) In Baimianshi orefield, main metallogenesis include three stages: the first stage is related to bimodal volcanism; the second one is related to Yanshanian magmatism; and the third is related to sub-volcanic rocks, and dikes (quartz porphyry and diabase).

(3) As per homogenisation temperature, salinity and composition, the fluids can be divided into four categories (6 sub-categories). Fluid contributing to metallogenesis are mainly mid-low temperature (270-350°C, 100-170°C), in which the salinity varies largely, indicating the mixture of high-salinity (15.5-16.5 wt%NaCl) and low-salinity fluids (0.5-1.5 wt%NaCl).

(4) On the whole, the metallogenesis of Baimianshi orefield appears to be effected by different ages of volcanic eruption, magmatic intrusions, and cross-cutting dikes, and the orebody is characterized by composite genesis.
Fig. 8 Uraninite distributed between inter-granule of quartz grains.

Fig. 9 The coexist of uraninite, pyrite and galenite.

Fig. 10 Uranium distributed in the cleavage of muscovite.

Fig. 11 Micro quartz containing pitchblende vein distributed between the intergranule and fracture of quartz grains.

Fig. 12 Uranium (white) distributed in the fracture of fluorite vein (black).

Fig. 13 Brannerite (light) located in the node of quartz (gray), and the black part of surface is chlorite.
REFERENCES

A special kind of sandstone type uranium deposit in Northeastern Ordos Basin, China

Z.Y. Li\textsuperscript{a}, X.H. Fang\textsuperscript{a}, Y. Sun\textsuperscript{a}, A.P. Chen\textsuperscript{b}, Y.Q. Jiao\textsuperscript{c}, Y.L. Xia\textsuperscript{a}, K. Zhang\textsuperscript{d}

\textsuperscript{a}Beijing Research Institute of Uranium Geology, Beijing, China
\textsuperscript{b}Geological Exploration Team 208, Inner Mongolia, China
\textsuperscript{c}China Geological University, Wuhan, China
\textsuperscript{d}Zhongshan University, Guangzhou, China

E-mail address of main author: zyli9818@126.com

\textbf{Abstract.} The large Dongsheng sandstone type uranium deposit was discovered recently in northeastern Ordos Basin, China. It is a unique kind of deposit, different from other known sandstone type deposits because of its distinctive signatures. It is generally controlled by a transitional zone between greenish and greyish sandstones, both indicating presently reduced geochemical environments. The greenish colour of the paleo-oxidized sandstones is mainly due to chloritization and epidotization related to oil and gas secondary reduction processes. The deposit, which is of more complex origin, has undergone not only paleo-oxidation mineralization process, but also oil-gas fluid and hydrothermal reworking processes and therefore is genetically different from other known sandstone uranium deposits. The metallogenic model for this uranium deposit is put forward, and exploration outcomes summarized in this paper.

\section{Introduction}

Dongsheng sandstone-type uranium deposit is a large deposit, recently discovered in the Jurassic Zhiluo Formation of northeastern Ordos Basin. The uranium mineralization occurs in the transitional zones between grey-green and grey sandstones of the Zhiluo Formation \cite{1}. The discovery of this uranium deposit, a very important energy mineral resource after oil-gas and coal deposits found in the basin, mark it as an “energy resources basin”\cite{1} \cite{2}. The sandstones both in oxidized and reduced ore zones show reduced colour of grey-green. That unique feature of this deposit is different from that of ordinary sandstone type uranium mineralization which occurs between oxidized yellow and reduced grey colour zones \cite{1}\cite{3}\cite{4}. Formation of Dongsheng sandstone-type uranium deposit and its unique metallogenic phenomena are closely related to the geological, structural and sedimentary evolution of the basin, as well as the geochemical conditions. Besides uranium deposits, there are large coal deposits found in Lower-Middle Jurassic Yan’an Formation and a number of oil and gas indications and occurrences in the study area \cite{5}\cite{6}\cite{7}\cite{8}. Therefore, to study the origin and establish metallogenic model is of not only important practical significance for further exploration, but also has theoretical significance for understanding the metallogenic processes and relationships with other energy mineral resources such as oil, gas and coal.

\begin{flushleft}
\footnotesize* Funded by both key national research and development plan project (code : 2003CB2146) and BOG uranium geological research project (code : HDKY20020501)
\end{flushleft}
2. Geologic setting

The study area is located at the southern margin of Yimeng uplift block in northeast Ordos Basin, adjacent to Hetao graben at the northern margin. Mesozoic sedimentary strata are mainly exposed in the study area (Fig. 1)[9]. The Upper-Triassic Yanchang Formation is mainly composed of gravel-bearing sandstone interbedded with siltstone and mudstones, bearing oil- and coal-deposits. The Lower-Middle Jurassic Yanan Formation is mainly composed of coal producing arkose, mudstone and siltstone. The Middle Jurassic Zhiluo Formation is the uranium-bearing host, composed of grey-green sandstone and mottled siltstone and mudstone, which is parallel or locally angular to the unconformably underlying Yanan Formation. The Anding Formation is composed of grey-green argillaceous sandstone, purple-red fine-grained sandstone, mudstone interbeded with white fine-grained calcareous sandstone, which is parallel to unconformably underlain by the Zhiluo Formation. The Upper Jurassic Fenfanghe Formation is poorly developed in the study area. The Lower Cretaceous strata are mainly composed of purple, grey-green sandy conglomerate, sandstone and purple-red, brown-red silt mudstone interbeded with thin beds of sandstone and conglomerate, which has angular unconformities with overlying and underlying formations [10][11]. The Tertiary strata are absent, the Quaternary sands and soils range from several to tens of meters in thickness. Sedimentary strata show that the study area underwent multiple tectonic events [6], and are closely related to uranium mineralization. Uranium mineralization occurs in the transitional zones between grey-green and grey sandstones of the Zhiluo Formation.

![Simplified geological map of Dongsheng area in Ordos Basin.](image)

*FIG. 1. Simplified geological map of Dongsheng area in Ordos Basin.*

1—Lower Cretaceous series, 2—Jurassic system, 3—Triassic system, 4—Paleozoic erathem, 5—Road, 6—Study area [12]

3. Petrology of ore bed sandstone

The host rock is a graded horizon with rhythmical change in grain size and cross-stratification. The grains are loosely cemented; the clastic grains are both poorly rounded and sorted, being mostly sub-angular to sub-rounded in shape. It is mainly composed of gravel-bearing grit, medium-coarse grained sandstone, coarse-grained sand bearing medium-grained sandstone, medium- and fine-grained sandstone. The mineral compositions are mainly quartz, feldspar, debris and mica.

The matrix in the sandstones are usually less than 10%, and carbonates less than 0.5%. Contact cementation dominates followed by the porous cementation in the matrix. Some sandstones are strongly altered by carbonatization, the contents of the carbonates range from 10% to 20%, in cases of basal cementation, the carbonate even up to more than 50%, forming “psammitic limestone”. Almost all of the carbonates exist as calcite. The calcite usually shows form of large bright crystal grains, in some cases micro-crystal aggregates ranging from 0.002 mm to 0.005 mm in diameters, and sometimes also spherulites, which should form later.
The host sandstones are quite complicated in mineralogical compositions, which are dominated by quartz, also containing a lot of feldspar, debris, mica and some heavy accessory minerals.

The host sandstones of the lower member of Zhiluo Formation are debris-bearing arkose with abundant feldspar clastics and debris in the study area, indicating fast deposition, in environments close to the provenance area. Major rocks of provenance areas are inferred to be granitic and metamorphic rocks, a few volcanic rocks according to the debris compositions.

4. Features of grey-green sandstone

Grey-green sandstone is located in north and northeast parts of the study area, surrounding grey sandstone as semi-circular and incising grey sandstone as a tongue in north-south section, which shows typical spatial distribution features of interlayered oxidation zone.

Hand specimen of grey-green sandstone looks compact and greenish in colour with different tones. Pyrite and carboniferous debris (or organic veinlets) could not be observed by naked eyes or even with hand lens. Further, a quite thin oxidized circle around the muddy gravel can be identified. Sometimes grey-green sandstone is interbedded by grey-purple calcareous sandstone with high content of carbonate, in which strongly oxidized carbonaceous plant clastics could be observed. These features confirm that grey-green sandstones underwent strong oxidation process prior to attaining the present grey-green colour [12]. The oxidized residues, which have not completely become greenish, are due to enclosing effect of strong carbonation.

Petrologic studies show that grey-green sandstone does not greatly differ from grey sandstone in mineral composition, only small difference in content of chlorite. Grey-green sandstone contains more chlorite than grey sandstone. Chlorite have been identified to be pennine and thuringite, their contents are usually less than 1%. The pennine can be considered to be alteration product of biotite, but thuringite is produced by alteration of plagioclase. However, most biotite are not altered, only some of them have been altered to be greenish biotite. In addition, some epidote and greenish illite in the matrix of sandstone can be identified. The greenish sandstones usually contain few pyrite grains. Some grey-green sandstones are strongly carbonatized, and biotite underwent locally strong oxidation and is replaced partially by carbonate. In addition, few ilmenite remains in the grey-green sandstone, being almost replaced by crystal druse of anatase.

The clay data indicate that grey-green sandstone has undergone stronger alteration than grey sandstone. The difference in clay composition between both kinds of sandstones is marked by content of kaolinite and chlorite. Kaolinite is richer in grey sandstone with average value of 45.0% than that in grey green sandstone with average value of 26%. However, the chlorite is just opposite, with average value of 3% and 20.75% respectively (Table 1). The scanning electron microscope (SEM) study shows that thin acicular-leaf and spheroidal chlorites cover the surface of grains in grey-green debris-bearing arkose (Fig. 2). So, it can be concluded that high content of chlorite is reason for greenish colour in those grey green sandstones.

Table 1. X-ray diffraction quantitative analysis of clay minerals

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Lithology</th>
<th>Relative content of clay minerals (%)</th>
<th>S</th>
<th>I/S</th>
<th>I</th>
<th>K</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave.(2)</td>
<td>Light grey medium-grained debris-bearing arkose</td>
<td>49.5</td>
<td>2.5</td>
<td>45</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ave.(4)</td>
<td>Grey-green medium-grained debris-bearing arkose</td>
<td>50.5</td>
<td>/</td>
<td>2.75</td>
<td>26</td>
<td>20.75</td>
<td></td>
</tr>
</tbody>
</table>

*analyzed in Experiment and Research Center of Petroleum Geology, Research Institute of Petroleum Exploration and Development, PetroChina. S: Smectite, I: Illite, K: Kaolinite, C: Chlorite
5. Origin of grey-green sandstone

The petrological, mineralogical and geochemical studies show that grey-green sandstones had undergone initial oxidation process and later second reduction process during geotectonic evolution [12].

Evidences of grey-green sandstones undergoing oxidation process in the initial stage are listed as follows:

1. They are located in north and northeast part of the study area, as semi-circular exposures surrounding grey sandstone and incising grey sandstone as a tongue shape in north-south section, which is typically the spatial distribution feature of an interlayered oxidation zone.

2. A thin oxidation layer around muddy gravel in grey-green sandstone can be observed, furthermore, the oxidized minerals and plant debris can be found in the impermeable matrix of calcareous sandstone interbeds because of carbonate alteration.

3. Compared with grey sandstone, the grey-green sandstone contains less pyrite and organic material, but higher content of clay minerals, and ilmenite is almost completely oxidized as well.

4. Geochemically, grey green sandstones contain lower sulfur and organic carbon, but higher Fe$\text{O}_3$/FeO ratio, which are in concordance with their mineralogical data. In addition, the ore element U and associated elements Mo, V etc. obviously move out.

Second reduction processes took place after the formation of uranium deposit in the Zhiluo Formation. These processes transformed the sandstones in the paleo-oxidation zone to green or grey-green colour, indicating geochemical reduction environments. The greenish colour mainly results from chloritization and epidotization. The ore bodies are clearly located in the transitional zone between grey and green coloured sandstones. This is a special feature of Dongsheng deposit, different from other sandstone type uranium deposits. As pointed out before, the greenish colour of grey-green sandstones is due to very thin layers of acicular-leaf chlorite around clastic grains. The second reduction process with alteration of chlorite is closely related to natural oil and gas. A lot of oil and gas inclusions have been found not only in the paleo-oxidation zone, but also in the ore body zone, which show multiple oil and gas incursions and and reworking processes [13][12].
6. Uranium mineralization

When uranium bearing fluids flow to the places where physical and chemical conditions change, stable and complex compounds become unstable and get precipitated. The importance in changing conditions of the uranium bearing fluids are the organic matter, which plays the reduction and absorption role.

In reducing conditions, adsorption by organic matter is related with humic and fulvic acids. The absorption of $\text{UO}_2^{2+}$ is determined by both enrichment of $\text{UO}_2^{2+}$ ion and the agglomeration degree of uranium organic complex compounds. In the acidic condition of $\text{pH}=3.4$, the adsorption of uranium is at the highest.

Nearly all solid bitumen and many kinds of coal (with humic acid) have ability to reduce uranium [14]. The materials which can reduce uranium are plant debris formed during sedimentation process, and bitumen and oil migrating into ore beds after diagenesis. The rate of reduction depends on the organic matter character and reaction temperature.

The study area has undergone a tecto-thermal event after uranium mineralization. Because of high temperature, the thermal fluids have strong migration ability and are rich in U, Mo, Re, V, Se, Si, Ti, P, REE etc. These fluids are usually alkaline. Under condition of strong oil reduction, fluid feature changes from alkaline to acidic and uranium precipitates from the fluids.

Dongsheng deposit occurs in the redox zone, i.e. transitional zone between oxidation and reduced zones. The redox transitional zone was formed by both paleo-phreatic and interlayer oxidation processes. So, it has both vertical and horizontal zonations [15], which are also under pinned by geochemical and mineralogical zonations. Analytical data for U, Se, Mo, V, Re and S show systematic increase from oxidation to original zones in both vertical and horizontal sections. Goethite, kaolinite, and hematite are typical in the oxidation zone, in contrast with pyrite in the original zone. The ore bodies show roll-front shape with long tails.

7. Metallogenic model

The formational conditions, controls and mineralization mechanism of the sandstone type uranium deposit in the northeastern Ordos Basin, are very complicated [16]. It underwent multiple mineralization processes, such as tectonic multi-periodic “dynamic-static” coupling movements, superposition of paleo phreatic oxidation and interlayered oxidation and composite transformation by oil-gas and thermal fluids[17][18]. Therefore, a metallogenic superposition model has been put forward for the deposit in the northeastern Ordos Basin (Fig. 3).
FIG. 3. Metallogenic model of Dongsheng sandstone type uranium deposit in northeastern Ordos Basin.

A: Preliminary enrichment stage; B: Paleo-phreatic oxidation stage; C: Paleo-phreatic+ Paleo-interlayer oxidation stages; D: Oil-gas reduction+ Thermal modification stages.

The grey sandstones of braided river facies in Zhiluo Formation is the host for uranium mineralization. They were deposited in humid condition favorable for development of reducing materials and initial uranium enrichment. The initial uranium enrichment of ore beds is one of important sources for uranium mineralization.

Paleo-phreatic oxidation process took place in middle and late Jurassic after the deposition Zhiluo Formation. This was due to up-lift of the basin and inclined movement coupled with paleoclimate change from humid to dry and semi dry, which is favorable for surface and vertical oxidization processes to develop, and uranium enrichment and mineralization began in the ore bed.
Paleo-interlayer oxidation process occurred in the late Jurassic to early Cretaceous. Uplift of the study area exposed to surface most part Zhiluo Formation, promoting weathering and oxidizing processes. When the paleoclimate was dry, oxygen- and uranium-bearing fluids moved into the ore beds and interlayered oxidation process led to development of uranium mineralization.

The multi-stage oil-gas reduction in the mineralized zones have been inferred from the many oil-gas inclusions, indicating its role in the uranium mineralization. Post mineralization tectonic movements, uplift and decompression lead to multiple oil-gas diffusions, which in turn promoted second reduction of ore beds, and transformed earlier oxidation zone to grey-green.

Analytical data show that thermal modification of the deposit happened Ca. 20-8 Ma after the deposit formed. It is probably due to this modification that coffinite (Fig. 4), selenium, sulfide minerals formed under relatively high temperature, leading to the superimposed enrichments of elements like P, Se, Si, Ti and REE over uranium. The complex uranium mineralization and modification processes make this deposit unique, different from other sandstone type uranium deposits. The presence of coffinite indicates that uranium mineralization formed at relatively higher temperature and more reducing environment than those of the other deposit. The higher temperatures are also evidenced from inclusion studies on vein carbonates ranging from 70°C to 170°C, and the salinity from 8% to 20%, which also indicate that Dongsheng area has been imprinted with hydrothermal events.

![FIG. 4. Coffinite crystal found in uranium ore sample.](image)

8. **Exploration criteria**

As discussed above, Dongsheng deposit is characterized by its unique features, which are related to its complicated origin. The deposit was formed not only under redox processes, but also underwent oil-gas and hydrothermal reworking. Therefore understanding of the genesis is of practical significance to exploration. Major criteria for exploration are:

1. **Tectonic slope:** The slope must have a favorable dipping angle not more than 10 degrees and should have undergone subsidence and uplift to maintain acceptable depth of target horizons and erosion period for uranium mineralization.

2. **Connected sandstone bodies and lithologically transitional zone:** Sandstone bodies should be well connected as stable horizons. Uranium mineralization often occurs in the transitional zones associated with lithologic, grain-size, facies or colour changes.

3. **Paleo-oxidization zones:** Greenish or green sandstones are special features, which reflect secondary reduction processes. They are actually secondary-reduced paleo-
oxidation zones. Uranium mineralization is controlled by transitional zones between grey (original rock) and green (paleo-oxidized) sandstones.

REFERENCES


Abstract. Since 1950s, many non-seismic geophysical survey techniques, such as radioactive geophysical survey method, induced polarization (IP), high resolution magnetic survey method, AMT and CSAMT have been applied and have played a very important role in exploration for hydrothermal uranium deposits in China. However, up to the early part of 21st century, seismic survey method has been hardly utilized in hydrothermal uranium deposits exploration. It is mainly due to the more complicated geological settings where hydrothermal uranium deposits occur compared to oil, gas or coal fields. These complicated geological settings include, for example, complicated ore shapes, small dimensions and as various lithologies are involved, wave impedance difference between the medium on each side of the interface is small. If the ground surface conditions are rough, there will be a lot of high-energy interference waves. Since 2007, based on studies of hydrothermal uranium ore formation mechanism and ground surface characteristics in uranium ore field, seismic work group of BRIUG has carried out a lot of systemic tentative work on excitation type of seismic source, layout of geophones, data analysis and processing techniques, and has obtained obvious success in detection of ore-control factors, such as basement or faults with high angle of inclination. We are sure that seismic survey method developed by BRIUG will become one of the most important technique for hydrothermal uranium deposits exploration in future.

1. Introduction

Due to poor surface conditions, large dip angle and small scale of the fault, as well as the marker horizon being not evident, for more than 50 years, seismic survey method has been hardly utilized in hydrothermal uranium deposits exploration in China. With the rapid development of nuclear industry in China, the demand for uranium resources has increased dramatically, and new geophysical methods and techniques should be developed to improve the efficiency of uranium exploration. Since 2007, based on studies on hydrothermal uranium ore formation mechanism and ground surface characteristics in uranium ore field, seismic work group of BRIUG has carried out a lot of systemic tentative work on excitation type of seismic source, layout of geophones, data analysis and processing techniques, and has obtained obvious success in detection of ore-control factors, such as basement or faults with high angle of inclination.

2. Methodology and advantages

2.1. Methodology

In general, the geologic environment of hydrothermal ore field are much more complex involving different approach than the conventional seismic survey used in oil and coal prospecting field. The surface conditions are complicated, dip angle of detecting target is large and the marker bed is not
evident, and all of those have brought great difficulties to the application of reflection seismic survey in hydrothermal uranium exploration. However, as the angle between ground surface and the fault is usually small, reflected wave of the fault could be directly received in a specific direction. The geological model for detection is shown in Fig. 1. Owing to the limitation of hillslope length, practical working modes adopted are: 1) Receiving terminal: geophones are of concentrated spread (Fig. 2), so that signal to noise ratio is higher; 2) Measurement mode: point measurement along the measuring line is adopted instead of CDP profile survey. By special processing of the acquired data extensions of the faults could be inferred.

1-middle coarse grained porphyritic two-mica granite  2-silicified zone  3-chalcedony vein 
4-fissure zone  5-hematitization  6-sericitization  7-kaolinization  8-chloritization 
9-fractured zone  10-gallery and its number  11-trench and its number  12-number of profile  13-grade of ore body (or mineralized)(%)/thickness(m)  14-orebody (or mineralized) and its number

2.2. **Advantages**

Advantages of this method are:

(1) **Strong adaptability**
Application preconditions for seismic survey are lowered, and application range of seismic survey is expanded. Fault detection could be performed in the area where the environment could hardly meet the demands of application preconditions for conventional seismic survey.

(2) **Strong pertinence**
Usually, field construction of seismic survey method aimed at detecting faults is carried out according to common depth point stack (CDP) technique along the measuring line. After corresponding data processing, it can tell whether or not there is a fault through events comparison.

(3) **High efficiency**
In this method, point-by-point moving technique of CDP method is not used and point measurement is adopted instead of profile survey, which could reduce workload and improve detection efficiency.

(4) **High signal-to-noise ratio**
Twenty four or more times stacking could be realized by making the geophones in form of concentrated spread, which is hard to be achieved through CDP method in a small site.

3. **Field methodology and results**

3.1. **Field methodology**

An experimental case study has been carried out on the known fault No.7 in a hydrothermal uranium ore field in south China (Fig. 3). Eight measuring points are located between P1 and P2. Space between two points is 10 meters and explosive mass is 1050 grams each time. Other acquisition parameters are listed as follows:

- Receiving channel: 24
- Offset: 20m
- Sampling interval: 0.5ms
- Record length: 1s

3.2. **Results**

As shown in the upside of Fig.3., time section could be plotted after format conversion, filtering and stacking processing. Obvious reflection events appear between 213 ms and 238 ms, and depths calculated are 502 meters (distance from P2 to the reflection surface) and 560 meters (distance from P1 to the reflection surface) respectively. Actual distances (which are calculated based on the geological profile provided by No. 261 Geological Brigade of Nuclear Industry) are as follows: about 556 meters from P2 to the reflection surface and its detecting error is 10.8%; about 634 meters from P1 to the reflection surface and its detecting error is 13.3%.
FIG. 3. Experimental result of unconventional seismic survey.
4. **Conclusions**

Based on the research result, it is thought that the newly developed seismic survey technique could be applied to detect faults in mountain areas. This technique can provide important evidences for uranium resources evaluation in hydrothermal uranium ore field by further improving the methodology. The details are:

(1) The detection result of a known fault by seismic survey technique indicates that not only reflected wave of the fault surface could be received, but also the error of vertical depth detected is less than 15%, and that will provide important information for geological evaluation of the work area.

(2) Concentrated spread of geophones makes it possible to realize multiple stacking in the work area of smaller range, and the signal-to-noise ratio is increased effectively, so detectability of this technique is improved.

(3) Valuable results could be obtained by improving data acquisition, data analysis and geological interpretation abilities of this technique.
Application of multi-source remote sensing information in uranium exploration

Y. Zhao, D. Liu, D. Lu
Beijing Research Institute of Uranium Geology, Beijing, China

Abstract. Uranium exploration needs new technology. Remote sensing technology are now being developed rapidly, including multi-spectral imaging, hyper-spectral imaging, radar etc., and as more and more information can be extracted from the images, they provide important means for uranium exploration. In this study, a new technology, optical-energy integration was developed, and the advantages of optical satellite remote sensing information and radioactive energy spectrum are utilized. Characteristics of lithology can be classified very well with the above technique.

1. Introduction

Commercial satellite technical capabilities presently include better spatial resolution, spectrum resolution and time resolution which are important in various applications. Currently, these capabilities are being developed very quickly in terms of higher spatial resolution, narrower spectrum bandwidth and shorter periods. In uranium exploration, the nature of spatial and spectrum resolution are more important, because it gives information of lithology, structure and alterations [1][2].

As the information received by the satellite sensors is surficial, water and vegetation can be recognized easily. Structures and terrains can also be identified. In many areas, because of the influence of vegetation, no distinct differences in the colour and texture of various rocks are visible. Therefore it is difficult to identify the lithology, though many processing routines for vegetation removal have been adopted. It is well known that the energy spectrum data can reflect the energy spectrum information of the rocks covered by vegetation, based on the content of U, Th and K in the rocks. So it is feasible to identify the lithology by using the energy spectrum. Good results have been achieved in the Lucong basin, Erdos basin and Lingquan basin in identification of different types of rocks by the colour on the composite images of U, Th and K and the cluster images, but it was difficult to determine the contact between different formations.

2. Geological setting

The Lucong basin of Anhui Province is located in the fault depression zone in the middle and lower reaches of the Yangtze River and is covered by thick vegetation, where the main strata are the Jurassic and the Cretaceous. The Middle Jurassic consists of sandstone of the Luoling Formation, which is distributed around the rim of the basin. The Upper Jurassic and the Lower Cretaceous are composed of volcanic rocks and intrusive rocks, and can be divided into four cycles, Longmenyuan, Zhuanqiao, Shuangmiao and Fushan, which consist of a suite of the mugearite system [3][4][5][6].

The Lingquan basin in Manzhouli, another study area, is located southeast of Manzhouli from Jalai Nur to Taodaoping. Volcanic rocks of the Jurassic and the Cretaceous are the main rock types in the basin. The Jurassic consists of lava and pyroclastic rocks, and can be divided into the Tamulangou and Shangkuli formations. The Cretaceous is composed of the Damoguaihe Formation, which is formed by conglomerate and sandstone. The basin is covered by thick vegetation.
3. Lithologic identification by the visible light-energy spectrum fusion technique

Visible light and energy spectrum are both characteristic information of the rocks, so there must be some intrinsic relation between them. This paper first discusses the relation between the light spectrum and the energy spectrum. The relations between the light and the energy spectrum data can be clearly seen from the tables, which indicates that they are indeed correlative. Factor analysis was used to reduce the number of variables to a few significant non-correlated factors, which can explain the total variation in the observation set. A new image, the light-energy image, was generated after the light spectrum and energy spectrum data were processed by the factor analysis, and histogram equalization applied on the composite image with three principal factors. This new image contains not only the light spectrum information but also the energy spectrum information. Different formations are shown in different colours and textures, so that the boundary lines between various formations can be interpreted. Besides, in the Lucong basin, the boundary between the Huangmeijian quartz syenite rock body and the volcanic rock can be clearly defined and the structures can be interpreted. In the Lingquan basin, with the same technique, different types of rocks were also identified. At the same time, Jurassic lava was found on the Yujishan beschtauite rock body, which was not marked in the original geological map. Field investigation has proven the results of interpretation by using the light-energy spectrum fusion technique are accurate. The fusion technique contains both the light and the energy spectrum information, and it is proven by its applications in the Lucong and Lingquan basins that different types of rocks can be identified, and therefore is a good method in uranium investigations.

FIG. 1. Landsat TM image of Lucong region (R: band5; G: band3; B: band1).

FIG. 2. Airborne radioactivity image of Lucong region (R: K; G: K/U; B: K/Th).

FIG. 3. Light-energy fusion image of Lucong region.

FIG. 4. Light-energy fusion image of Lingquan region.
4. Techniques in multi-source remote sensing in uranium exploration

Multi-spectral data are collected in several bands with low spatial resolution and large coverage, eg., Landsat, SPOT, ASTER. Multi-spectral data can be used to interpret structure [7].

Hyper-spectral remote sensing represent the important future trend. It can analyze components of surficial matter and classify it in detail. Hyperspectral imaging can be used in mineral mapping based on characteristic spectrum of rock or strata. Examples of commercial hyper-spectral sensors are MODIS and Hyperion. It is believed that hyper-spectral remote sensing will play a very important role in uranium exploration.

Compared with optical remote sensing, SAR can collect data in all-weather and day and night. But, SAR image is more difficult to process and visually interpret because of noise. Radar signals can penetrate through top layers in arid areas, and hidden fault can be revealed in Zhungeer basin of Xinjiang, TM image and JERS radar image are fused using HIS transform, and the hidden fault identified (Fig. 5).

*FIG. 5. Landsat TM image of Zhungeer in Xinjiang (Left).\nFusion image of TM and JERS radar image (Right).*

The application of remote sensing in uranium exploration must also be combined other geo-data, such as geo-map, DEM, airborne magnetic data and these data or information can be managed by GIS tools (Fig. 6).
5. Conclusion

The paper discussed techniques to recognize lithology through multi-source remote sensing data, such as multi-spectral image and airborne radioactivity data. A new image is generated by fusion of two kinds of data and good results are obtained.

The advantages of three kinds of remote sensing image are also summarized. The techniques of using multi-source remote sensing image in uranium exploration is put forward.

REFERENCES


Uranium mineralization in late Cretaceous sandstones in parts of Meghalaya, India

P.S. Parihar\textsuperscript{a}, R. Mohanty\textsuperscript{b}, A. Majumdar\textsuperscript{c}

\textsuperscript{a}Atomic Minerals Directorate for Exploration and Research, Hyderabad, India
\textsuperscript{b}Atomic Minerals Directorate for Exploration and Research, Shillong, India
\textsuperscript{c}Atomic Minerals Directorate for Exploration and Research, Nagpur, India

E-mail address of main author: addldir-op2.amd@gov.in

Abstract. Late Cretaceous Lower Mahadek sandstone of Meghalaya has been established as the potential host rock for sandstone type of uranium mineralisation in India. To date, nearly 16 000 tonnes of U\textsubscript{3}O\textsubscript{8} reserves have been estimated in four locations viz., Domiasiat, Wahkyn, Tynrai and Lostoin, in the southern part of Meghalaya plateau. The uranium investigations are primarily confined to the areas where the Lower Mahadek sandstones are exposed either on the surface or along deep river cuttings, otherwise concealed by thick cover of Tertiary sediments. The area poses major logistical challenges due to thick forest and remoteness. Out of nearly 1 800 km\textsuperscript{2} of extent of the Mahadek Basin, only 28\% of the area exposes Lower Mahadek sediments. The discovery of uranium mineralization so far achieved, is confined to the exposed area. Survey in recent years has also established a few more occurrences at Umthongkut, Wahkut and Rongcheng Plateau in Balphakram area. These occurrences exhibit very strong uranium mineralization on the surface and are technically ripe for exploratory drilling. Large scale exploratory drilling is planned in these areas, which may substantially add to the uranium resources of the region. Systematic study of available surface and subsurface data has revealed that mineralization is controlled by palaeo channel configuration of Mahadek sediments and also the typical geochemical interface. Regional and local tectonics also have played an important role in distribution and concentration of uranium mineralisation in the area. It is observed that the deposits and the very promising occurrences described above fall strikingly along an E-W lineament. Litho-structural studies indicate that the southern block appears to have gone upwards relative to the northern block in contrast to other such signatures in the area. This might have influenced ground hydrodynamic flow pattern and helped in concentration of uranium. The Lower Mahadek sandstones, host rock of these deposits are mostly sub-arkosic to arkosic, grading sometimes to felspathic arenite. The main uranium minerals are pitchblende, coffinite and organo-uranyl complex. Uranium mineralization is associated with bituminous organic matter occurring as dense inclusions, isolated clusters and lumps of various sizes and as clayey – dusty organic matter associated with cementing material. The work so far has been confined to the shallower part of the basin (28\% of the total area). There is no reason not to believe that many more concealed deposits in the remaining 72\% of unexposed Lower Mahadek sediments may be present. Multidisciplinary investigations have been initiated to locate such concealed occurrences. Geophysical investigations, mainly magnetic survey is in progress in some identified blocks in the area between Wahkyn and Umthongkut which are otherwise covered by 300-400 m thick Tertiary sediments. Such surveys would help in delineating magnetic lows which indirectly points to the presence of buried palaeochannel. Integrated Remote Sensing studies using high resolution satellite data of IRS LISS-III and LISS-IV are being undertaken to delineate broad lithological and structural patterns between Umthongkut and Wahkyn. The role of neo-tectonics in disposition of Lower Mahadek sandstone is being evaluated prior to taking up deeper subsurface exploration. Thus, the Lower Mahadek sandstones covered by thick Tertiary sediments in the larger part of the Mahadek basin are being probed by indirect techniques in order to discover more sandstone type of uranium deposits in Meghalaya.
1. Introduction

Mahadek basin of Meghalaya plateau in northeastern India is identified as a ‘Uranium Province’ [1] wherein, two sizeable deposits of economic grade (Domiasiat and Wahkyn) and four satellite deposits (Gomaghat, Tyrnai and Philandiloin and Lostoin) have already been established. The Mahadek sediments are exposed along the southern fringe of Meghalaya Plateau over a 180 km length stretch from Lumshong of Jaintia Hills in the east to Balphakram of South Garo Hills in the west with an average width of 10 km (see Fig. 1). The Mahadek Basin covers about 1 800 sq km (8%) area of Meghalaya state and out of this, about 500 sq km (28%) area exposes Mahadek sediments, which have been largely explored. Uranium bearing Lower Mahadek sediments are considered to be predominantly fluvial, whereas the Upper Mahadek sediments are deposited under fluviatile to marginal marine environment. Over the last four decades, nearly 250 uranium occurrences of varying dimension and grade hosted by the Lower Mahadek sandstone have been discovered (see Fig. 1).

Systematic multidisciplinary studies [2][3][4] have defined many fundamental aspects on geology, sedimentology and uranium exploration in the Mahadek formation such as (i) recognition of fluvial component of the Mahadeks, (ii) its division into two members Lower and Upper Mahadeks (reduced and oxidized facies respectively) and (iii) characterization of ore grade mineralization and its geomorphic expression, (iv) fertile nature of the provenance and (v) role of organic matter.

![FIG. 1. Regional geology of Meghalaya.](image)

This paper describe the potential of uranium mineralisation in the Mahadek Formation of Meghalaya and the multidisciplinary exploration strategy to identify exploration targets in the areas covered by thick Tertiary sediments in the light of the experience gained over the past four decades.

2. Geology

Meghalaya Plateau is considered to be an uplifted horst-like feature bounded by major tectonic features like Brahmaputra lineament in the north, Dauki fault in south, Haflong Fault in the east and Rajmahal-Garo gap in the west. The plateau is considered to be the northeasterly extension of the Indian Peninsula and comprise Archaean gneisses/schist and Palaeo– Meso–Proterozoic Shillong Group of rocks with intrusive Neo-Proterozoic granite plutons [5]. Prominant granitic plutons are
South Khasi Batholith (690±19 Ma), Mylliem (607±13 Ma), Nongpoh (550±15 Ma) and Kyrdem (479±26 Ma) granites [6]. Uplift of the Meghalaya Plateau commenced in Late Jurassic period, associated with extrusive Sylhet traps which culminated during the Cretaceous period. Granite and granite gneisses are the dominant rock types in the basement with high intrinsic uranium content of 8 to 59 ppm and form the fertile provenance for Mahadek sediments.

A generalized stratigraphic succession modified after Geological Survey of India 1974 [5] is given in Table 1.

Table 1. General stratigraphic succession

<table>
<thead>
<tr>
<th>Era/Period</th>
<th>Group</th>
<th>Formation</th>
<th>Member/Beds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miocene</td>
<td>Garo</td>
<td>Chenganpa 700m</td>
<td>Sandstone, siltstone, clay and marl</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Baghmara 530m</td>
<td>Feldspathic sandstone, conglomerate and clay</td>
</tr>
<tr>
<td>Palaeocene</td>
<td>Jaintia</td>
<td>Kopili-Rewak 500m</td>
<td>Shale, sandstone and marl</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shella 600m</td>
<td>Alternations of sandstone and limestone</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Langpar 50-100m</td>
<td>Calcareous shale, sandstone and impure limestone</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>Khasi</td>
<td>Mahadek 215m</td>
<td>Upper: purple, coarse to fine arkosic purple sandstone, arkose (Ca. 190m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jadukata 235m</td>
<td>Lower: grey, coarse to medium grained feldspathic sandstone, arkose (25 - 60m)</td>
</tr>
<tr>
<td>Jurassic</td>
<td>Sylhet</td>
<td>Sylhet Trap</td>
<td>Basalt, alkali-basalt and acid tuff, alkaline rocks and carbonatite complexes</td>
</tr>
<tr>
<td>Neoproterozoic</td>
<td>Intrusive</td>
<td>Kyrdem Granite</td>
<td>Coarse porphyritic granite, pegmatite, aplit and quartz vein. Epidiorite and dolerite</td>
</tr>
<tr>
<td></td>
<td>Granites</td>
<td>Nongpoh Granite</td>
<td>Quartz arenite, arenite and quartzite</td>
</tr>
<tr>
<td>Palaeo-Mesoproterozoic</td>
<td>Shillong</td>
<td>Barapani (Arenaceous)</td>
<td>Quartz arenite, arenite and quartzite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tyrsad (Argillaceous)</td>
<td>Phyllite, quartzite, mica schist</td>
</tr>
</tbody>
</table>

3. Uranium mineralization

The Mahadek Formation is divided into two members. The Lower Mahadek member consisting of medium to coarse grained, grayish-green to dark gray, immature feldspathic sandstone with abundant carbonaceous matter and pyrite and tuffaceous matter [7] having average thickness of 20 to 60m. The lithologic units are deposited in a fluviatile environment and occur as channel fill, cross-bedded, unsorted grayish feldspathic arenite to quartz arenites, predominantly composed of clast and a little matrix (<10%) with cement and clays in varying proportion. Quartz is predominant component followed by minor feldspar, rock fragments, garnet and accessories like zircon, monazite, rutile, sphene and opaques (oxides and sulphides). It also contains varying proportion of organic matter. Pyrite is of both biogenic frambooidal and melnicovite type. The main uranium mineral is pitchblende and minor phases include coffinite, uraninite, brannerite, U-Si-C, which occur as clusters, blebs and botryoidal forms intimately associated with migratory coaly matter (0.5 to 5%) and biogenic pyrite (0.5 to 1%). Repeated remobilization and deposition processes resulted in the formation of rich grade uranium deposit at Domiasiat [8]. The carbon isotopic values ($\delta^{13}C$) falling between -17.1 to -23.4 % (relative to PDB standard) indicate abundance of algal plant material [9]. Host rock and mineralization characteristics of the six uranium deposits established so far in this province are listed in Table 2.
Table 2. Characteristics of U deposits in Mahadek basin, Meghalaya

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Domiasiat</th>
<th>Wahkyn</th>
<th>Gomaghat</th>
<th>Tyrnai</th>
<th>Phlangdiloin</th>
<th>Lostoin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Host Rock</td>
<td>Feldspathic quartz arenites &amp; Arkosic sediments</td>
<td>Arkosic to subarkosic Sandstone</td>
<td>Feldspathic wacke</td>
<td>Medium to coarse grained sandstone</td>
<td>Feldspathic sandstone</td>
<td>Arkosic to subarkosic Sandstone</td>
</tr>
<tr>
<td>Nature of orebody (see Fig.2)</td>
<td>Tabular/Pene- concordant</td>
<td>Tabular/Pene- concordant</td>
<td>Tabular/Pene- concordant</td>
<td>Tabular/Pene- concordant</td>
<td>Tabular/Pene- concordant</td>
<td>Tabular/Pene- concordant</td>
</tr>
<tr>
<td>Dimension (m)</td>
<td>1700 x 200</td>
<td>1300 x 1000</td>
<td>1300 x 900</td>
<td>1000 x 500</td>
<td>2000 x 500</td>
<td>1200 x 400</td>
</tr>
<tr>
<td>Mineralogy</td>
<td>Pitchblende, Coffinite</td>
<td>Pitchblende, coffinite, U+Ti+Si Complex</td>
<td>Uraninite, Cofinite, Torbernite, Pyrochlore</td>
<td>Pitchblende, Coffinite, U+Ti+Si Complex</td>
<td>Pitchblende, coffinite, organo-uranium compound, zircon and monazite</td>
<td>Pitchblende, coffinite, U+Ti+Si Complex</td>
</tr>
<tr>
<td>Associated elements</td>
<td>V, As, Co, Mo, Se(Tr.)</td>
<td>V, Co, As, Se, Mo</td>
<td>V, Cu, Pb, Se, Mo</td>
<td>V, Cu, Pb, Se, Mo</td>
<td>Cu, V, Mo, Cr, Ga, Ti, Zr, Th</td>
<td>V, Co, As, Se, Mo</td>
</tr>
<tr>
<td>Grade %UO₃</td>
<td>0.104</td>
<td>0.101</td>
<td>0.048–0.036</td>
<td>0.102</td>
<td>0.101</td>
<td>0.064</td>
</tr>
<tr>
<td>Thickness (m)</td>
<td>4.07</td>
<td>3.41</td>
<td>1.41–2.03</td>
<td>1.53</td>
<td>1.8</td>
<td>1.5</td>
</tr>
<tr>
<td>Uranium Reserves</td>
<td>Medium tonnage</td>
<td>Medium tonnage</td>
<td>Low tonnage</td>
<td>Low tonnage</td>
<td>Low tonnage</td>
<td>Low tonnage</td>
</tr>
<tr>
<td>Disequili-brium</td>
<td>15% towards U</td>
<td>32-44 % towards U</td>
<td>20% towards U</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Leachability</td>
<td>92-96%</td>
<td>80 – 87 %</td>
<td>N.D</td>
<td>N.D</td>
<td>N.D</td>
<td>N.D</td>
</tr>
<tr>
<td>Organic matter</td>
<td>0.5–&lt;1%</td>
<td>&lt;1 to 5%</td>
<td>N.D</td>
<td>N.D</td>
<td>N.D</td>
<td>N.D</td>
</tr>
</tbody>
</table>

- **FIG.2. Correlation sections, Killung Block.**
4. Umthongkut – Balphakram – The emerging prospect

The recent discovery of uranium mineralisation in the Lower Mahadek member at Umthongkut in the West Khasi Hills district and Balphakram in the South Garo Hills district [10][11] (see Fig. 3) has opened up vast areas for uranium exploration in the western part of the Mahadek Basin. Significant uranium mineralisation was recorded in Umthongkut sector over a dimension of 1 500 x 300 m x 1-15 m [11]. Sixteen radioactive occurrences were found exposed along the escarpment/nala sections to the west of Umthongkut village. Pitchblende and coffinite were identified as major radioactive minerals.

The potential area between Wahkyn South and Umthongkut has been taken up for multidisciplinary and subsurface exploration. Recently, integrated geophysical investigations and remote sensing studies were initiated on a wider scale between Wahkyn and Umthongkut area which are otherwise covered by 300-400 m thick Tertiary sediments. The studies have indicated the significant role that tectonics have played in uplift/downthrow of lithological units and redistribution of associated uranium mineralization. These areas are under active exploration to augment the uranium resources of the Mahadek Basin.

![GEOLOGICAL MAP OF PARTS OF GARO HILLS AND WEST KHASI HILLS SHOWING MAHADEKS AND TERTIARIES](image)

FIG. 2. Geological map Umthongkut and Balphakram areas.

5. Ore geometry and genesis

The general geometry of ore bodies in the Mahadek Basin is tabular/penepcordant. The depth to the ore bodies varies generally between 30 to 50 m, occasionally up to 212 m. Medium to large lenticular bodies, disposed in en-echelon pattern are normally intercepted but at some places ore bands are persistent over 500 to 1 000 m. The ore zone thickness varies from 1.50 to 5m. Lower Mahadek member hosts most of the uranium deposits/occurrences, where uranium mineralisation is intimately associated with reductants, such as organic matter and pyrite. However, at Gomaghat redox interface
has played an important role in concentration of uranium in fluviatile to marginal marine sediments of distal facies.

Bulk of uranium is introduced into the basin from extrinsic sources. South Khasi Batholith, Mylliem granite and migmatite containing anomalous uranium content of 7–110 ppm are noted in the provenance which supplied uranium rich detritus to the Mahadek Basin. Continued subsidence of the basin pari-passu with sedimentation ensured speedy burial of the sediments which arrested the oxidative decomposition of the organic matter and facilitated conversion of the vegetal matter into coaly/carbonaceous substances and formation of diagenetic pyrite thus creating reducing environment for later uranium precipitation from solutions. It is also believed that oxygenated acidic ground water leached labile uranium from the overlying sediments that percolated down along hydraulic gradient encountering reducing environments. Continued upliftment of Meghalaya plateau may also have provided oxygenated ground water causing further remobilization and precipitation as per the multiple migration accretion hypothesis of Gruner. Uranium ore genesis in Mahadek Basin can be summarized as i) uranium is derived from the fertile basement provenance mostly from granitic and migmatitic terrain with minor basic components; ii) uranium is transported from the source to the depositional locales by circulating mildly acidic ground water through permeable horizons of Lower Mahadek sediments; iii) uranium in the mineralised solution is reduced by the organic matter or by adsorption mechanism; iv) high concentration of uranium up to the ore grade levels is formed due to multiple migration and accretion and deposited in suitable locales along paleo-channels having favourable conditions, as discussed above.

6. Geophysical studies

Ground geophysical surveys, mainly magnetic and resistivity soundings were initiated over an area of about 20 km length between Wahkyn and Umthongkut. The area was taken up on the basis of the results of the drilling data at Wahkyn uranium deposit in the east and discovery of significant uranium occurrences at Umthongkut in the west. In the Wahkyn area it has also been established that the palaeo-channels trending NW-SE and NE-SW controlled the uranium mineralisation. The faults/fractures in the basement granite-gneisses might have also been transformed into channels in which greater thickness of Lower Mahadek sediments is expected and greater porosity and permeability along these palaeo-channels may act as loci for mineralizing solutions. Hence locating major structural features within the basement and depth of the basement are the targets for geophysical surveys in the area [12].

The magnetic anomaly map of a part of the area indicated the well developed E-W trending low with associated high which is interpreted as a signature of the Chira fault, a major lineament along which lie most of the significant uranium occurrences in the Mahadek Basin. The change in the trend of the contour pattern within this magnetic low (NE of Porawdher) might be due to the combined effect of the E-W trending Chira fault and NW-SE trending Porjri lineament. A magnetic low in NE of Kulang corresponding to another magnetic high at Pakut (Nongjri) is also established.

7. Exploration strategy and challenges

In the western part of the Mahadek basin the Lower Mahadek member, the host for uranium mineralization, is by and large concealed below the Tertiary sediments of 300-400 m thickness and poses challenges for the survey and exploratory drilling programme in the basin.

The paleo-channels and the basement lows which have been established as the receptacles of better grade mineralization are also difficult to locate under the thick Tertiary cover sediments. Therefore, integrated ground geophysical and remote sensing studies are being used to identify targets for exploration in these areas. Vast inputs of heliborne geophysical surveys, including Time Domain Electro Magnetic, Gamma Ray Spectrometric and Magnetic methods are to be deployed in this basin. Airborne and ground based geophysical surveys are expected to generate huge volume of data for delineation of favourable areas for mineralization. Poor communication and infrastructure facilities coupled with adverse public opinion with respect to uranium exploration are other challenges. The
host Mahadek Formation exposes only along the steep escarpments and stream sections. The sedimentological studies such as, lithofacies mapping, size analysis and heavy minerals studies can only be practiced in a limited area for identification of the target areas.

8. Conclusions

Uranium exploration in Mahadek basin of Meghalaya Plateau has continued over the last four decades. Sustained efforts have resulted in identifying favourable target horizons hosting sandstone type uranium mineralisation. The discovery of uranium deposits at Domiasiat and Wahkyn, besides four smaller satellite deposits have established Mahadek Basin as a Uranium Province for sandstone type deposits in India. The deposits are well understood and controls have been well defined. The uranium mineralisation in Mahadek sediments is controlled by several factors like fluvial character and proximal facies of sediments, mode of occurrence of organic matter, nature of source rocks and basement topography and these parameters have greatly helped in mobilization and fixation of uranium. The favourability factors present in Lower Mahadek Formations point towards the likely addition of more medium size and medium-grade sandstone type deposits in these sediments. There are prime target areas at Umthongkut, Balphakram and between Wahkyn and Umthongkut where large scale drilling is contemplated to prove additional uranium resources. Multidisciplinary integrated studies are being utilised in this geologically favourable terrain, covered by Tertiary sediments, to demarcate sites for subsurface exploration.

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REFERENCES

Proterozoic unconformity related uranium mineralization in the Srisailam and Palnad Sub-Basins of Cuddapah Basin, Andhra Pradesh, India

U. Konka, K.K. Achar, P.B. Maithani

Atomic Minerals Directorate for Exploration and Research / Department of Atomic Energy, Hyderabad, India

Email-address of main author: kumamaheswar.amd@gov.in

Abstract. The intracratonic, Mesoproterozoic Cuddapah basin has been identified as one of the promising targets for locating unconformity related uranium mineralization in India. Two sub-basins, namely, Srisailam and Palnad lie in the northern part of the basin, with arenaceous, argillaceous and calcareous sediments resting on basement granitoids of Archaean to Paleoproterozoic age, basic dykes of Paleoproterozoic age and greenstone belts of Archaean age. Exploration in northern parts of Srisailam sub-basin has established three small tonnage, medium grade uranium deposits at Lambapur, Peddagattu and Chitrial, Nalgonda district, Andhra Pradesh. Exploration efforts in the northwestern margin of Palnad sub-basin has resulted in locating a low-grade small tonnage uranium deposit at Koppunuru, Guntur district, Andhra Pradesh. Uranium mineralization in the Srisailam sub-basin is mainly confined to the fractured basement granites close to unconformity, with shallow depth persistence. These deposits occur as elongated pods proximal to the unconformity, with richer pockets at the intersection of N-S, NNE-SSW and NW-SE trending fractures. Pitchblende is the main uranium mineral identified which is closely associated with drusy quartz, galena, chalcopyrite and pyrite. Illitization and chloritization are the common alteration features observed. In the Koppunuru uranium deposit of Palnad sub-basin three distinct uranium mineralized bands, hosted by quartzite/shale, gritty-quartzite and altered basement granites have been delineated. Pitchblende and coffinite are the primary uranium phases associated with pyrite and carbonaceous matter. Mineralization occurs in the form of fine veins, fractures, cavities and grain boundary fillings. The southward continuity of the litho-structural setup associated with uranium deposits in both sub-basins along with favorable factors, such as the Paleoproterozoic fertile, fractured granitoid basement, Meso-Neoproterozoic cover rocks and repeated phases of tectonic activity, indicate the potentiality of both these sub-basins to host more such deposits. Airborne, ground geophysical and geochemical surveys are planned to locate concealed unconformity type of uranium deposits in the deeper parts of these sub-basins.

1. Introduction

Unconformity related uranium deposits constitute the most promising large tonnage, high grade uranium resources of the world. These deposits typically occur as fracture/brecchia fillings in Paleoproterozoic metapelites and arenaceous Mesoproterozoic cover sediments close to the unconformity [1][2][3]. Search for such deposits was initiated in several Proterozoic basins of India since 1990. Consequently, the Meso-Neoproterozoic Cuddapah basin in the eastern Dharwar Craton of peninsular India was identified as one of the promising targets for locating such deposits. Srisailam and Palnad sub-basins lie in the northern margin of Cuddapah basin, exposing the sediments of Meso-Neoproterozoic Cuddapah Supergroup and Neoproterozoic Kurnool Group respectively. Intensive uranium exploration in these sub-basins has resulted in identifying substantial uranium reserves in four deposits namely Lambapur, Peddagattu, Chitrial in Nalgonda district and Koppunuru in Guntur district. Subsurface exploration is still being carried out to establish additional uranium resources in the adjoining areas of these deposits and in the deeper parts of these sub-basins.
2. Geology and structure

2.1. Regional geological setting

The crescent shaped Cuddapah basin (Fig. 1), having an extent of 44 000 sq km, contains over 12 km thick sequence of sedimentary and volcanic rocks belonging to the Meso-Neoproterozoic Cuddapah Supergroup and Kurnool Group. The western margin of the basin is marked by a nonconformity, with the formations resting on Archean gneisses, narrow linear greenstone belts and granites of Paleoproterozoic age. The eastern margin of the basin is marked by a thrusted contact, where the older Achaean gneisses / Dharwar metasedimentary rocks are thrust over rocks of the Cuddapah basin [4]. The Cuddapah Supergroup is predominantly arenaceous to argillaceous, with subordinate calcareous to dolomitic units; developed in Papaghni, Nallamalai and Srisailam sub-basins, whereas, carbonate facies sediments are developed in Kurnool and Palnad sub-basins.

In the northern margins of Cuddapah basin, the basement comprises Archean schist (Peddavoora Schist belt) and gneisses, Paleoproterozoic granite, basic dykes, pegmatites and quartz veins. Three generations of basic dykes are observed in the basement mostly trending N-S/NNE-SSW, E-W/ENE-WSW and NE-SW; which are also the trend of major fractures/faults. Major faults affecting the basement, as well as, overlying sediments generally trend NNE-SSW and ENE-WSW.

2.2. Srisailam sub-basin

Neoproterozoic Srisailam Formation, the youngest unit of Cuddapah Supergroup, developed in the Srisailam sub-basin forms a prominent plateau with an extent of around 3 000 sq km in the northern part of Cuddapah basin. It is mainly an arenaceous unit with subordinate shale intercalations. The sediments display sub-horizontal dips due southeast, and attains a maximum thickness of 300 m [4].

Along the northern margins, the sediments of Srisailam Formation directly overlie the basement rocks consisting of Archean gneisses and granites of Paleoproterozoic (2 268±32 Ma to 2 482±70 Ma) age [5]. In the southeastern margin, the Srisailam Formation is underlain by Nallamalai Group metasediments with an angular unconformity (Fig. 2). In its northern fringes the Srisailam sub-basin has a highly dissected topography with several flat topped outliers occurring within the basement and rising 100 to 150 m above ground level. The Lambapur, Peddagattu and Chitrial uranium deposits are located in three such separate outliers detached from the main Srisailam sub-basin.

![FIG. 2. Geological map of northern part of Cuddapah Basin.](image)

2.3. Palnad sub-basin

The Neoproterozoic Palnad sub-basin (Fig. 2) extends over 3 400 sq km and comprises arenaceous, argillaceous and calcareous sediments (equivalent to Kurnool Group in main Kurnool sub-basin) unconformably overlying basement granite/gneisses. The sediments comprise Banganapalle quartzite/shale, Narji limestone/calcareous shale, Owk shale and Paniam quartzite. The thickness of the sediments varies from 10 m to 450 m, with gentle south easterly dip. The basement granite/gneisses are essentially composed of quartz, plagioclase and alkali feldspars along with biotite, apatite monazite and allanite as accessories. Basic dykes (<1m to 60m width) trending N-S, E-W & NW-SE and quartz veins trending N-S, traverse the basement rocks.
3. Uranium mineralization

Uranium anomalies located by ground radiometric surveys, along the unconformity between basement granite and overlying Srisailam sediments in the Lambapur outlier, in the northern fringes of the Srisailam sub-basin, [6] led to the first major breakthrough in the search for unconformity related uranium deposits in the Cuddapah basin. Detailed exploration at Lambapur and in adjacent outliers resulted in establishing three uranium deposits at Lambapur, Peddagattu and Chitrial. Continuity of litho-structural set up and proximity of the major uranium deposits in the Srisailam sub-basin to the adjacent Palnad sub-basin, led to extension of uranium investigations into the Palnad sub-basin as well. This eventually resulted in establishing the Koppunuru uranium deposit; close to the unconformity between the basement granite and sediments of Kurnool Group [7]. Salient features of the deposits in both sub-basins are discussed below.

3.1. Lambapur - Peddagattu-Chitrial uranium deposits in Srisailam Sub-basin

Lambapur, Peddagattu and Chitrial uranium deposits have similar lithostructural setup and nature of uranium mineralization with comparable geological and geochemical controls. The basement granite has been characterized as biotite-granite, essentially containing quartz, orthoclase, microcline, perthite, biotite and plagioclase. Apatite, zircon and allanite are the other accessory minerals present, whereas, chlorite, sericite, calcite and epidote are the secondary minerals formed due to alteration. Pyrite, chalcopyrite, galena, ilmenite, anatase and hydrated iron oxides are the opaque minerals observed. The uranium content of the granites varies from 10 to 116 ppm with U/Th ratios ranging from 0.34 to 2.32. Geochemical studies of the granites of these areas indicate that they are potassic (K_2O/Na_2O >1), peraluminous (A/CKN: 1.05-2.18) and low Ca-granite, without showing significant differentiated character and probably formed by partial melting of silicic crustal material [8].

The basement granites/gneisses are intruded by three prominent sets of basic dykes trending NNW-SSE, NW-SE and N-S, which are older to the Srisailam Formation [9]. The Srisailam Formation generally starts with a pebbly gritty arenite horizon, overlain by shale and shale/quartzite intercalations, followed by massive quartzite. The thickness of the Srisailam Formation varies from 5-70 m with gentle dips of 3° to 5° towards southeast.

In all the deposits, uranium mineralization occurs close to the unconformity, both in the basement granites and the overlying Srisailam pebbly arenite, with most part (>85%) in the former unit (Fig. 3). Basic dykes and vein quartz within the basement, close to the unconformity, are also mineralized at places. Lead and copper mineralization is also associated with vein quartz. Features of hydrothermal activity, both in the basement and overlying sediments, is evidenced by high amounts of sulphides. Fluid inclusion studies of quartz occurring in mineralized granite indicate that highly saline solutions of 100-200°C temperature are responsible for deposition of uranium. Sm-Nd isochron dating of uraninite from Lambapur area indicates an age of 1327±170 Ma, whereas, U-Pb data yield radiogenic Pb ages of about 480-500 Ma [10].

Exploration by core and non-core drilling at regular grid of 400 m x 400 m, 200 m x 200 m and 100 m x 100 m over the entire Lambapur, Peddagattu and a part of Chitrial outliers has indicated that the ore shoots are confined to NNE-SSW, N-S and NW-SE trends. Owing to the pronounced control of both the unconformity plane and the fractures in the basement, the ore body is in the form of lenses and elongated pods, with rich ore shoots at fracture intersections [11]. The intensity of fracturing apparently controls the loci of mineralization and the grade. The mineralization is attributed to presence of botryoidal and massive pitchblende in fractures / segregated masses in feldspars and along weak planes. Coffinite is found marginally replacing massive pitchblende at places.

Nearly 14 000 t of U_3O_8 has been estimated in the three deposits of Srisailam sub-basin. Of the three, the Lambapur uranium deposit has been studied in detail and exploration of the deposit is complete, whereas it is on-going in the other two outliers. Systematic and integrated exploration is in progress in contiguous areas as well, to establish additional uranium resources.
3.2. Koppunuru uranium deposit in Palnad Sub-basin

The Koppunuru-Dwarakapuri uranium deposit falls in the western part of the Palnad sub-basin which comprises Neoproterozoic Kurnool Group of sediments [12]. The Archaean Gneisses and Paleoproterozoic basement granites are nonconformably overlain by the sub-horizontal Kurnool Group of sediments. Basement granite is also exposed as an inlier, extending over an area of 6 km x 2.5 km, to the east of Koppunuru and along the up thrown block of the regional WNW- ESE trending Kandlagunta fault. This fault is in turn offset by younger north-south trending minor faults (Fig. 4). The basement rocks and the overlying Banganapalle Formation are fractured and traversed by quartz veins trending N-S, NNE-SSW and WNW- ESE. The Banganapalle quartzites are grey coloured, well sorted and sacchroidal in nature with high degree of mineralogical maturity and are composed of sub-rounded clasts dominantly constituted by quartz (97%) and feldspar (3%) [13]. Basement granites plot mainly in the ‘granite’ field and subordinately in ‘quartz-monzonite, granodiorite and tonalite’ fields in Ab-An-Or space [14]. In Rb-Ba-Sr space [15] most of the samples plot in ‘normal’ to ‘anomalous’ granite fields with a few in strongly differentiated granite field. The basement granite, is characterized
by higher intrinsic uranium (Ave. 32 ppm; n=16) and with high U/Th ratios (Ave. 4.41; n=16) as compared to the average uranium and U/Th ratio of normal granite (U/Th =0.25).

Subsurface exploration by drilling in Koppunuru area reveals fracture controlled correlatable uranium mineralization hosted by Banganapalle Formation, as well as, the basement granites. Three sub-horizontal ore lodes have been established; two of which are in the arenite facies and the third one in the basal polymictic grit/conglomerate of Banganapalle Formation, at places transgressing along the fractures into the underlying basement granites. About 2 300 t of U3O8 has been estimated in Koppunuru block.

Primary uranium minerals identified in Koppunuru are pitchblende and coffinite occurring as stringers and veins. Pitchblende occurs as colloform aggregates and veinlets often showing coffinitization; secondary uranyl minerals occur along margins of detrital clasts. Traces of carbonaceous matter are associated with uranium mineralization along with sulphide minerals.

**FIG. 4.** Geological map showing distribution of ore bodies in Koppunuru area, Guntur district, Andhra Pradesh and section along C-D.
Uranium metallogeny at Koppunuru is attributed to the remobilization of uranium from the fertile basement granite, as a consequence of episodic reactivation of pre-existing faults in post-Kurnool times. Major among these are the WNW-ESE trending Kandlagunta fault and the N-S to NNE-SSW trending fault east of Koppunuru (Fig. 4.). The basal polymictic conglomerate, deposited as a channel lag deposit and porous sacchroidal quartz arenites, with grey carbonaceous shale intercalations, with associated sulphide minerals, were favourable hosts for the uranium mineralization. Fractures, fine veins, cavities and grain boundaries in the basement/sediments, proximal to the unconformity plane, trapped the labile uranium resulting in its precipitation. Hence mineralization at Koppunuru area is characterized as low temperature-epigenetic type of uranium mineralization.

4. Discussion

The Cuddapah basin in the eastern Dharwar craton of peninsular India holds high potential to host unconformity related uranium deposits, although some of the salient geological features (such as the different nature of the basement) of the classical unconformity type of deposits are absent in the Cuddapah basin. However, the northern margin of the Cuddapah basin hosts unique uranium deposits in Lambapur, Chitrial and Peddagattu in Srisailam sub-basin and Koppunuru in Palnad sub-basin.

With a view to locate additional such deposits, ground radiometric surveys were carried out in the remaining outliers and along the margins of main Srisailam sub-basin. This resulted in locating a number of uranium anomalies; significant among them being the Amrabad and Akkavaram anomalies (Fig. 2). Similarly, ground radiometric surveys along the northwestern margin of Palnad sub-basin revealed presence of a number of uranium anomalies; in the basement granites proximal to the unconformity. Significant among them is the Musi river anomaly, Damaracherla sector. Intensive sub surface exploration is envisaged in these areas.

5. Conclusion

The uranium deposits at Lambapur, Peddagattu and Chitrial in Srisailam sub-basin and Koppunuru in Palnad sub-basin are mainly confined to the unconformity plane between the Paleoproterozoic fertile, fractured granite and Meso-Neoproterozoic arenaceous facies cover rocks. The mineralization is associated with the basement fractures, basic dykes, carbonaceous matter and extensive alteration. The main ore minerals are uraninite, pitchblende and coffinite, which are generally associated with sulphides like pyrite, pyrrhotite, galena, chalcopyrite and pentlandite. The mineralization is low temperature hydrothermal in nature.

The southward continuity of the lithostructural setup of known uranium deposits in both sub-basins such as the Paleoproterozoic basement, Meso-Neoproterozoic cover rocks, increase in thickness of cover sediments (>300m) and repeated tectonic activity indicate the potentiality of these subbasins to host more uranium deposits. In this light, air borne, ground geophysical and geochemical surveys are planned to obtain signatures for possible concealed uranium deposits, at greater depths in both Srisailam and Palnad sub-basins of Cuddapah basin.

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REFERENCES


Prospects and potentialities for uranium in North Delhi Fold Belt: 
A case study from Rohil, Rajasthan, India

L. K. Nanda\textsuperscript{a}, V. J. Katti\textsuperscript{a}, P. B. Maithani\textsuperscript{b}

\textsuperscript{a} Atomic Minerals Directorate for Exploration and Research, Jaipur, India
\textsuperscript{b} Atomic Minerals Directorate for Exploration and Research, Hyderabad, India

Abstract. North Delhi Fold Belt (NDFB) of Western Indian Craton consists of Palaeo–Meso Proterozoic volcano–sedimentary rocks of Delhi Supergroup deposited in a half graben. These rocks have undergone polyphase deformation, metamorphism and intrusion by late granites. Younger pegmatite, aplite and albitite occur along major structural breaks. The three sub–basins of NDFB comprise Khetri, Alwar and Lalsot–Bayana. The Khetri sub–basin forms an important metallogenic province and hosts important uranium and base metal resources. A NE–SW trending prominent crustal scale fracture system, known as Kaliguman lineament, tectonically separates Delhi Supergroup metasediments from basement rocks. Widespread zone of albitization along this lineament, with 170 km strike extent, is popularly known as “albitite line”. Since 1950, more than a hundred U and Th anomalies, associated with structurally weak zones in metasediments have been reported in NDFB. One such zone at Rohil hosts a low tonnage, low grade uranium deposit. This deposit comprises five sub–vertical, en–echelon ore lodes occurring over 340–686 m strike with average thickness of 4.27 m. Major uranium mineral is uraninite with minor brannerite, coffinite with common association of chalcopyrite, pyrrhotite, molybdenite and pyrite. The mineralized rocks exhibit strong hydrothermal alterations like chloritization, silicification, ferruginization and albitization. The uraniferous samples contain significant levels of Cu, Mo, Ni, Co and Pb. Preliminary Pb isotopic ratios indicate age of uraninite as $839\pm19$ Ma. At Rohil, uranium ore lodes extend below surface to 600 m depth. Coincidence of strong EM conductivity, high chargeability and low magnetic intensity with uranium lodes have successfully guided application of ground geophysical exploration programme in contiguous alluvium–covered blocks. Further, for quicker delineation of favourable targets in the Khetri sub–basin, multi–parameter high–resolution heliborne geophysical surveys have been completed over 105 km × 15 km and anomalous zones identified. Mathematical modeling of exploration data may be applicable in effective exploration planning.

1. Introduction

In the Western Indian Shield of Rajasthan important uranium occurrences are associated with metasediments of Palaeo–Meso Proterozoic Delhi Supergroup in North Delhi Fold Belt (NDFB) [1][2][3]. Exploration activities in NDFB by the Atomic Minerals Directorate for Exploration and Research (AMD) dates back to 1950s [4]. These resulted in identification of numerous uranium occurrences at Rohil, Ghateshwar, Diara, Saladipura, Kerpura, Hurra ki Dhani, Maonda, Pachlangi, Khetri, Kolihan, Sior, Siswali, Antri–Biharipur, Mewara–Gujarwas, Ladi Ka Bas, Kalatopri, Kho–Dariba, Dhani Basri, Bairat and other areas (Fig. 1). The Khetri sub–basin of NDFB, which is well known for base–metal mineralization, also hosts innumerable uranium occurrences in shear zones forming prominent lineaments. The mineralized shear/fracture zones follow NNE–SSW trend, within the zone of albitization better known as ‘albitite line’ of Rajasthan [5][6]. The albitite line follows Khetri lineament in northeast and Kaliguman lineament in southwest (Fig 2). Several post–Delhi granitic bodies are emplaced along this lineament.

Integrated exploration over the years has brought to light one ore block of 700 m (length) × 200 m (width) × 600 m (depth) dimension, containing low tonnage, low grade uranium deposit at Rohil, in the southwestern part of Khetri sub basin (KSB). This paper deals with the polymetallic mineralization at Rohil with association of U, Mo, Cu, Ni, Co, Pb, and Zn. The success of delineating uranium
deposit at Rohil is based on integrated geological and geophysical exploration and drilling. The heliborne geophysical data generated over the NDFB resulted in identification of several areas suitable for detailed investigations.

**FIG. 1.** Regional geological map of NDFB showing location of important radioactive anomalies.
2. Geological setting

The rocks of Palaeo–Meso Proterozoic Delhi Supergroup form a narrow belt extending from Haryana in the north to Gujarat in the south [7]. This belt has been divided into North Delhi Fold Belt (NDFB) and South Delhi Fold Belt (SDFB), separated by a migmatitic gneiss track around Ajmer [8][9]. The NDFB consists of three sub–basins designated as Khetri, Alwar and Lalsot–Bayana from west to east, respectively. The generalized stratigraphy of the NDFB is presented in Table 1.

The Archaean Banded Gneissic Complex (BGC≡Mangalwar Group) comprising high–grade metamorphic and migmatized rocks form the basement. It is unconformably overlain by dominantly calcareous metasediments of Raialo Group. The Raialo Group in turn is unconformably overlain by arenaceous metasediments of Alwar Group. The metapeelites of Ajabgarh Group show gradational contact with the Alwar Group. The rocks of Delhi Supergroup are metamorphosed up to amphibolite facies.

The rocks record imprints of three phases of deformation of Delhi orogenic cycle. The folds of earlier generations (F₁ and F₂) are coaxial with broad NNE–SSW axial trends, forming prominent lineaments. The first generation (F₁) folds are isoclinal and second generation (F₂) folds are normal, upright to inclined with shallow to moderate plunge due NNE/SSW. The third phase of deformation has resulted in folds (F₃) with WNW–ESE trending axial planes and has caused broad swing in trends from NNE–SSW to NNW–SSE. Cross folding has resulted in development of doubly plunging synforms and antiforms [10].

The NDFB has witnessed post–Delhi acidic and basic magmatic activities. Rb–Sr studies on granites of KSB yield an age of 1 463±71 Ma with initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.7313±0.0024 (MSWD=24). Sm–
Nd model age on these granites vary from 2 204 to 2 335 Ma. Two major phases of acid intrusives are 1 480±40 Ma for Saladipura granite equivalent [11] and ~ 700 Ma for younger Malani igneous suite. The older granites are peraluminous with distinct S–type characteristics [12]. Biotites of older granites recorded thermal activity around 700 Ma [4], corresponding to Pan African event.

Albitite intrusives are widespread along NNE–SSW trending zone over an extent of 170 km with maximum width of 10 km. This zone, defined as the albitite line, follows Khetri and Kaliguman lineaments. In the Rb–Sr plot, albitites of KSB align along 1 400 Ma line. The albite and microcline from albitised pegmatite indicate Rb–Sr model ages of 464 to 671 Ma, respectively [13]. The albitised pegmatites are dated as 550±26 Ma and 477±9 Ma by Rb–Sr method, with initial \(^{87}\text{Sr}/^{86}\text{Sr}\) ratio of 0.74134±0.00060 (MSWD=6.26) and 0.73644±0.00049 (MSWD=3.82), respectively [14]. Opinions vary for origin of albitites, one school of thought emphasizing magmatic origin [5] and others advocating metasomatic concept [15][16][17].

Table 1. Generalised stratigraphy of North Delhi Fold Be

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<tr>
<th>Delhi Supergroup (Palaeo–Meso Proterozoic)</th>
<th>Post–Delhi Intrusives</th>
<th>Amphibolite Granule, aplite, pegmatite</th>
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<td>Ajabgarh Group</td>
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3. Uranium exploration history in the KSB

The uranium exploration history in the KSB dates back to 1950s and has been carried out in three discrete phases. The first uranium anomaly associated with the flesh coloured quartzo–felspathic rock occurring at the contact of epidiorites and carbonaceous phyllite was located in 1950–51 at Kolihan mines. Several other occurrences were located in the KSB, including Rohil–Ghateshwar anomaly in 1953–54. In 1955, shallow boreholes drilled at Ghateshwar intercepted lean grade uranium mineralization. During 1956–1962, in Kolihan area, lean uranium mineralization associated with quartzo–felspathic body was intercepted. Identification of brannerite, limited strike length, lensoidal nature of the ore body and poor grades resulted in closing of this phase of exploration.

In the second phase during 1972–73, underground drilling work was taken up in the Kolihan mines. Significant widths of radioactive horizon i.e. up to 15m in boreholes from 424 m level were intercepted. Surface drilling revealed a radioactive band with 200 m strike length, 140 m slope width and 2.50 m average thickness. A total reserve of 140 tonnes of \(\text{U}_3\text{O}_8\) was estimated under inferred category. Reconnoitory drilling in Siswali and Sior intercepted lean mineralization in most of the boreholes. In the year 1973, while prospecting for molybdenum in Ghateshwar area, the Geological Survey of India (GSI) drilled many boreholes. Gamma–ray logging of these boreholes by AMD
revealed encouraging results and uraninite was identified. During 1973–76, boreholes drilled in Ghateshwar by AMD intercepted lean mineralization which resulted in closure of phase II.

In Phase III, during 1994–95, radiometric ground checking of 500 sq km of the NDFB was carried out. Discovery of uraniferous chlorite schist, confirmation of uraninite as the principal radioactive phase in Kerpura, Hurra–ki–Dhani and Maonda areas and location of new anomalies associated with albities gave boost to the exploration programme. A 50 km long and 6 km wide belt was defined as a potential target for detailed uranium exploration [16]. In the period 1994–96, subsurface investigations were carried out at Diara and Kerpura–Narsinghpur–Tiwari ka bas. Lean mineralization was intercepted in some boreholes. One of the anomalies at Rohil was taken up for detailed exploration and evaluation work in the last decade. Besides, exploratory/reconnoitry drilling has been carried out in contiguous areas at Kerpura, Raghnathgarh and Ladi–ka–bas areas.

3.1. Uranium mineralization in KSB

In the KSB more than 250 radioactive occurrences have been located by ground radiometric surveys. The radioactivity is largely due to uranium mineralization with rare instances of small contribution due to thorium. The mineralization, hosted by a wide spectrum of lithologies encompassing quartz–biotite schist, quartzite, calc–silicate, quartz albitites/albitites, phyllites (± carbonaceous), granites, mafic rocks and quartz–feldspatic injections, is associated with polymetallic sulphides in sheared and altered zones.

Extensive exploration efforts have been made by integrated geological and geophysical investigations and drilling at Rohil, resulted in establishing a sizeable uranium deposit. The characteristics of Rohil uranium deposit are therefore, discussed in detail in a separate section.

4. Alwar sub–basin

In the Alwar sub–basin, large number of radioactive occurrences are associated with granitic and pegmatitic intrusives and hydrothermal veins in granites and metasediments. Uranium investigations were mainly confined to shear zones cutting across basement rocks as well as the Delhi cover sediments. Shear zones traversing basement rocks in Dhani Basri area host uranium and copper mineralization. Investigations along Dariba shear zone of Kho–Dariba area resulted in identification of significant uranium anomalous zones. In Bairath granite, a number of radioactive zones have been located; most of them associated with ferruginous cherty/quartz breccia and sheared granite, nearer to the contact with quartzite.

5. Bayana– Lalsot sub–basin

In this sub–basin, limited radiometric surveys have been undertaken. The area remains unexplored and possibility of locating uranium mineralization is high along the unconformity between basement and rocks of Delhi Supergroup as well as along fractures within the metasediments.

6. Rohil uranium deposit

6.1. Location

Rohil is situated in Sri Madhopur Tehsil of Sikar district in Rajasthan. The district is well connected by national and state highways. Rohil village around which the exploration blocks lie, is approximately 120 km from Jaipur.

6.2. Geology of Rohil

The area around Rohil is mainly covered by 40 – 50 m thick soil/alluvium with a N–S trending sub vertical sheared quartz ridge of 500 m × 200 m. The sheared eastern and western contacts of the quartzite with quartz–biotite schist show hydrothermal alterations viz. albitization, chloritization and
silicification. The lithounits comprise quartzite/amphibole quartzite, quartz–biotite ± amphibole ±
chlorite ± garnet ± graphite schist, carbonaceous/ graphitic phyllite, calc–silicates/impure marble.
These are traversed by quartz reef/vein, calcite, pegmatite, aplite, albite, amphibolite and
hornblendite. Rohil uranium anomaly is of limited extent and is confined to the eastern sheared
contact. The geological succession of the area based on subsurface data is presented in Table 2.

Table 2. Geological succession at Rohil

<table>
<thead>
<tr>
<th>Age</th>
<th>Supergroup</th>
<th>Group</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent</td>
<td>Alluvium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Proterozoic</td>
<td>Post–Delhi</td>
<td>intrusives</td>
<td>Quartz/calcite carbonate veins</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Granite/pegmatite/aplite/albitite</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Metabasites/amphibolite (hornblendites)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Quartzite</td>
</tr>
<tr>
<td>Palaeo–Meso Proterozoic</td>
<td>Delhi</td>
<td>Supergroup</td>
<td>Quartz–biotite–schist ± carbonaceous /</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>graphite schist with intercalatory bands of</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>quartzite, and calc–silicate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Unconformity</td>
</tr>
<tr>
<td></td>
<td>Basement not exposed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6.3. Uranium mineralization

Uranium mineralization at Rohil is structurally–controlled, hydrothermal vein–type and occurs in the
form of lodes, veins and lenses, confined to shear/fracture zones in quartz–biotite schist ± graphite,
quartzite, carbonaceous phyllite and calc–silicates. Hydrothermal alterations are manifested as
chloritization, albitization, feldspathization and silicification. Five sub–parallel, sub–vertical uranium
lodes occur in an en-echelon pattern along N–S to NNE–SSW trending Rohil shear zone defined by
brecciated and silicified quartzite ridge, having sheared contact with schistose rocks on two sides
(Fig 3).
Ore lodes have been delineated up to a depth of 600 m from surface by core drilling and a block of 700 m × 200 m × 600 m is identified as a potential deposit for exploitation. Individual lodes with average thickness of 2.4 m to 6 m have strike extents of 350 to 700 m. Horizontal separation of adjacent lodes vary between 6 m and 50 m, and the extreme lodes have separation between 80 to 200 m. The ore body has been established between depths of 80 m and 600 m from surface, with apparent further down–depth continuity [18].

Uranium minerals are mainly uraninite with minor coffinite and brannerite. The uraninite occurs as clusters, dissemination of anhedral grains filling polymetallic veins and as minute inclusions in biotite. Common association of chlorite, fluorite, calcite and goethite can be frequently noticed. The uraninite grains are often rimmed by chlorite, pyrite or chalcopyrite. The primary fluid inclusions in quartz, occurring in uraninite veins are largely biphase containing a H$_2$O rich liquid and a vapor bubble and in rare cases triphase inclusions containing a daughter crystal of NaCl. The fluid inclusions vary in size from 5µm – 9µm with 0.5–0.9 degree of fill. Majority of the inclusions homogenize at 200°C – 350°C. Salinity estimates obtained by heating–freezing data range between 15 – 40 wt% eNaCl. Preliminary investigation of uranium mineralized borehole core samples gave Pb–Pb isochron ages of 817±29 Ma to 839±19 Ma with $\mu_1$ values of 8.96±0.9 & 7.70±0.8, respectively [13].

Different sulfide mineralization episodes in KSB resulted in richer concentrations of pyrite, chalcopyrite with minor pyrrhotite and molybdenite. The petromineralogical study indicated three phases of sulfide mineralization in Rohil area. Pyrite with minor ilmenite occurring as disseminations in Delhi metasediments is the dominant constituent in the pre–uraninite phase. The ore stage is characterized by association of uranium mineralization with polymetallic sulfides along veins. This stage shows characteristic association of uraninite with molybdenite, chalcopyrite, pyrite and pyrrhotite. The post–uraninite phase shows association of pyrite and chalcopyrite.

The metasediments, especially rich in carbonaceous matter, contain high intrinsic uranium with values up to 36 ppm U$_3$O$_8$. During different phases of metamorphism, deformation and igneous activities, uranium from country rocks probably got remobilized and concentrated along structurally weaker shear and fracture zones. The late–phase igneous activity in the form of albite, pegmatite, aplite and basic intrusions (hornblendites and amphibolite) has played an important role in remobilizing uranium from the metasediments, besides acting as a possible source. Though, the uranium occurrences are confined to the albite line in KSB, uranium mineralization is not directly attributed to the regional albitionization episode [19].

### 6.4. Associated ore mineralogy

Uraninite, normally occurs in polymetallic veins in association with molybdenite, chalcopyrite, pyrrhotite and pyrite with gangue of chlorite, fluorite, calcite and goethite. It is often rimmed by chlorite, pyrite or chalcopyrite. The sulfide minerals occur in pre–, syn– and post–uranium ore stages. Pyrite is the main pre–ore stage mineral and has formed during syn–sedimentary volcanogenic Delhi sedimentation. The host rocks for uranium minerals, their mode of occurrence and associated mineralogy is summarized in Table 3.

### 6.5. Ore body configuration

Detailed systematic drilling in a block of 1 000 m × 600 m size followed by correlation of geological features and mineralized bands have been utilized in the delineation of ore body configuration and establishing a low grade (0.062%U$_3$O$_8$), low tonnage (3 720 tonnes U$_3$O$_8$) uranium deposit in Rohil. The deposit has an average thickness of 4.27 m. Five vertical to sub–vertical ore lodes have been delineated, out of which A & B are main lodes and A$_1$, B$_1$ and B$_2$ are subsidiary lodes (Fig 4). These lodes are parallel to sub–parallel, occur in an en-echelon pattern with maximum strike extent varying from 340 m to 686 m, and have been traced up to 600 m below surface. Conformity and best disposition of ore lodes at 300 m RL is observed in level plans (Fig 4). Sheared contact of quartzite with schist is very significant for mineralization (Fig 3) and acts as an important guide in exploration.
in adjoining blocks. The eastern contact is relatively richer in uranium mineralization compared to the western contact.

**FIG. 4. Ore body plan at 300 m RL, Rohil deposit**

<table>
<thead>
<tr>
<th>Host Rock</th>
<th>Uranium Minerals</th>
<th>Mode of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albitite &amp; quartz–albitite</td>
<td>Uraninite</td>
<td>Polymetallic veins comprising uraninite ± pyrite ± chalcopyrite ± pyrrhotite ± arsenopyrite ± molybdenite ± ilmenite ± fluorite. Uraninite &amp; brannerite as cubic to anhedral disseminations.</td>
</tr>
<tr>
<td>Albitised quartz–biotite± chlorite± plagioclase± tremolite± graphite schist</td>
<td>Uranninite coffinite</td>
<td>Composite veins of uraninite ± pyrite ± chalcopyrite ± magnetite. Uraninite as clusters and disseminations of anhedral grains.</td>
</tr>
<tr>
<td>Albitised calc–silicate rocks</td>
<td>Uraninite</td>
<td>Composite veins of subhedral – anhedral uraninite ± pyrite ± pyrrhotite ± molybdenite ± ilmenite. Cuboid uraninite rimmed either by chlorite, pyrite or chalcopyrite.</td>
</tr>
<tr>
<td>Albitised quartz–hornblende cataclasite</td>
<td>Uraninite</td>
<td>Composite veins of uraninite ± molybdenite ± pyrite ± ilmenite.</td>
</tr>
<tr>
<td>Breccia</td>
<td>Adsorbed uranium</td>
<td>Uranium adsorbed on hydrous iron oxides.</td>
</tr>
<tr>
<td>Albitised quartzite</td>
<td>Uraninite</td>
<td>Uraninite as minute inclusions in biotite and as anhedral disseminations associated with pyrite.</td>
</tr>
</tbody>
</table>
6.6. **U–Mo–Cu association**

Chemical data for core samples from ore zones of Rohil deposit indicate that besides uranium, copper and molybdenum occur in substantial concentration with an average of 1438 ppm Cu (n=1185) and 328 ppm Mo (n=971). In the samples analyzed, maximum values obtained are 21,119 ppm Cu and 15,390 ppm Mo. The average content of other metals are Ni (193 ppm, n=1014), Co (208 ppm, n=1078), Pb (268 ppm, n=388), and V (293 ppm, n=1095).

The noteworthy features observed are that with increase in the U₃O₈ grade, (a) Fe₂O₃ content increases which can be related to chloritic and haematitic hydrothermal alteration and explains the possibility of enhanced uranium grades with increasing proportion of alteration mineralogy or the degree of hydrothermal alteration (b) Cu content though not directly related to the U₃O₈ grades, shows higher concentration with average of 1438 ppm in uranium lodes (c) Mo content shows direct relation with U₃O₈, with significantly higher concentration with average of 921 ppm in samples having more than 0.10% U₃O₈. Values of Ni, Co and Pb also show increasing trend with U₃O₈ grades. However, their concentrations are not very significant from economic viewpoint. Zn and V are also not significant and do not show any systematic relation with the U₃O₈ grades [19].

6.7. **Ground geophysical survey**

Initial success was met by core drilling in an otherwise thickly soil/alluvium covered area at Rohil. For further systematic planning of expensive drilling programme, ground magnetic, gravity, IP, resistivity and TURAM surveys were carried out, simultaneously with drilling. Presence of graphitic schist, sulfides in the ore zone, quartz reef/quartzite and disseminated sulfide in metasediments have produced characteristic geophysical signatures.

The regional gravity and magnetic contours follow a NNE–SSW trend parallel to strike of formations. The gravity high over Rohil has been attributed to intrusive amphibolite bodies within metasediments and possibly also to sulfides in the mineralized zones. A prominent magnetic low (–450 nT to –200 nT) characterizes the Rohil shear zone.

A prominent zone of high chargeability (30 to 80 mV/V) and low resistivity (10 ohm.m) has been delineated over a strike length of 1.3 km, coinciding with the magnetic low zone. TURAM survey has led to identification of four N–S trending conductors. One of the EM conductor axes falls in the ore zone. Other conductors either follow sulfide–rich zones or graphitic schist (Fig. 5).

Thus, the ore zone at Rohil, as established by extensive core drilling, is characterized by association of strong EM conductor, low magnetic, high chargeability, low resistivity and high gravity geophysical anomalies [20]. The integrated geophysical data has helped in delineation of favourable targets for exploratory drilling in contiguous blocks.
FIG. 5. Rohil block showing geophysical anomalies district Sikar, Rajasthan.
6.7.1. Mathematical modeling of ground geophysical and heliborne magnetic data

The mathematical surface fitting for ground total magnetic intensity (TMI), resistivity and chargeability data has been carried out for Rohil area. The Natural Neighbour method of interpolation of data has been found to give the best statistical results on comparison with the original data.

Trend surface analysis was performed to examine the ‘regional trend’ of variation of the geophysical parameters. Residual plot providing ‘highs’ and ‘lows’ of the local anomalies were then estimated and plotted [21].

TMI residual plot distinctly shows Rohil ore block as a low magnetic zone. Relatively low residuals are also obtained in the North, South and NNE of Rohil area, which assume significance in uranium exploration. Heliborne TMI data for the block also gives similar features. The 2\textsuperscript{nd} order polynomial produces fairly good trend surface for TMI data with a 54.10\% goodness of fit.

The residual plot of ground resistivity, defines shear zone as distinct low resistive zone. Ground resistivity data, however, does not produce good trend surface and is interpreted to be due to a very large contrast of resistivity between the shear zone material and the surrounding country rocks. Even with fourth order polynomial, less than 15\% goodness of fit is achieved.

The chargeability residual map shows ‘high’ in the Rohil ore block and also in areas further to the SSW and to the NNW of Rohil, indicating presence of high chargeability material such as disseminated sulfides, graphite and finer grained hydrothermal alteration minerals of the shear zone. Cubic polynomial surface produces a reasonable goodness of fit of 36\% for ground chargeability data.

It is thus apparent that the mineralized area around Rohil is characterized by the associated geophysical anomalies of high chargeability, low resistivity and low total magnetic intensity (Fig. 6).
7. Identification of new prospecting areas – heliborne geophysical surveys

Heliborne multisensor multiparameter geophysical surveys consisting of aero–magnetic, EM (Frequency domain) and AGRS carried out in parts of NDFB, resulted in identification of a number of favourable targets in the extension areas of Rohil uranium deposit for uranium exploration [22]. A number of concealed faults/fractures have been inferred from aeromagnetic data. Clusters of conductors roughly scatter along NW–SE direction. The area around Gauti is inferred as an interesting target based on processing and interpretation of magnetic, EM and AGRS data. The EM–conductors identified in this zone do not display characteristics of any sheet-like conducting saline/brackish ground water, rather, these are segmented in linear zones and are expressions of geological features related to bed rock conductivity [23]. Some of these inferred conductors are being tested by exploratory core drilling.

8. Discussions

KSB is well known for copper and uranium mineralization along NE–SW trending lineaments. The 20 km long Rohil – Kotri – Guhala sector, where many uranium occurrences were delineated, is being investigated by integrated exploration techniques and targets have been identified. Similar geological cum structural set up continues further in the NE and SW extensions. Three sub–parallel belts with known uranium anomalies within KSB are considered as prime targets for vein type deposits [24]. This includes the areas in the NE and SW extensions of the relatively well explored Rohil area, Ladi ka Bas and Arath areas to the east and west of Rohil, respectively.
Exploration data indicate high probability of existence of concealed uranium deposits akin to Rohil in Rohil North Extension, Diara–Kotri, Kerpura–Salwari, Hurra ki Dhani and Raghunathgarh–Udaipurwati sectors.

As a part of integrated exploration inputs in delineation of potential target for sub-surface investigation in parts of NDFB, heliborne geophysical surveys have been completed. Magnetic, EM and gamma–ray spectrometric data coupled with satellite imageries are being utilized in narrowing down favourable areas for ground geophysical investigations such as detailed magnetic, EM, resistivity, gravity and IP surveys with follow–up exploratory drilling. Subsurface exploration in contiguous and extension areas of Rohil deposit by exploratory core drilling is currently under progress to augment uranium resources of NDFB.

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REFERENCES


On-line measurement of uranium in ores using XRF analyzer P2 Con-X

D. Docenko, V. Gostilo, A. Sokolov, A. Rozite

Bruker Baltic, LV-1005, Riga, Latvia

E-mail address of main author: office@bruker-baltic.lv

Abstract. We describe various possibilities of application of the conveyor belt X-ray fluorescence (XRF) analyzer P2 Con-X for on-line analysis of uranium in various raw materials.

Quantitative analysis is shown to be possible from 100 ppm up to 80% of uranium and more. Specific examples are given. Rapid ore separation based on uranium composition is also possible with P2 Con-X.

1. Introduction

It is known, that activity of uranium raw materials is rather low - several hundred quanta per second at 2-4% enrichment [1][2]. On this reason, equipment for control of such materials by natural radioactivity should be very sensitive.

In [3] we reported about development of high sensitive HPGe gamma-spectrometer with high energy resolution which provides control of the equitable distribution of uranium in mixed powders and tablets before putting them into fuel rods and the final quality inspection of the completed fuel rods. High sensitivity gamma spectrometers [3][4][5] can also be used for technological controls on the natural activity of uranium-containing liquid and gaseous flows for the intermediate stages of the uranium raw materials reprocessing.

X-Ray fluorescence analysis (XRF) is another technique which can be used for control of uranium raw materials. The on-line XRF analysis is currently a rapidly developing field thanks to recent technological and computational advances that allows use of the traditional, well-tested techniques in harsh industrial conditions [6]. Nowadays, on-line XRF analysis offers:

- simultaneous measurement of concentrations of many elements (up to 20 and more);
- quantitative analysis from tens of ppm to 95% and more;
- sub-percent analysis precision and accuracy;
- non-contact analysis that does not disturb the material stream;
- high representativity of the analysis;
- measurement time from tens of milliseconds to several minutes;
- operation in a wide range of external conditions;
- safety and simplicity in operation and service.

On-line analysis of material composition becomes possible only if the results are independent on variations of external parameters, such as temperature and humidity of the analyzed material and the analyzer environment, variations of the material lump size and height, etc.

The P2 Con-X 02 analyzer has been created accounting for all these features [7]. Its probe is situated in a hermetic enclosure with stabilized temperature inside the detection system that ensures reliable measurement results at most environmental conditions (Fig.1). Specially designed software uses the
X-ray spectra to account for changes in the distance to the measured material, thus providing the user with the correct results irrespectively of the material flow level. Variations in the humidity levels are also accounted for, if they are found to affect the measurement results.

![FIG. 1. On-line analyzer P2 Con-X 02 in operation.](image)

2. **Analysis of uranium as trace element**

Uranium is rather widely distributed as a trace element with an average crust content around 1.8 ppm, but for economically effective beneficiation much higher uranium concentrations are needed.

The P2 Con-X on-line XRF analyzer is able to detect and estimate uranium content in various materials, even if it is only moderately concentrated compared to the average crust composition.

For example, in five minutes of measurement, Th and U spectral lines are clearly visible in a rutile sample (consisting of mostly TiO$_2$ sand), where the uranium concentration is of the order of 100 ppm (Fig.2). The detection limit in this case is about 60 ppm. Also in other sample types (e.g., in zircon, ZrSiO$_4$) detection limits are roughly the same.
FIG. 2. Rutile XRF spectrum showing main components (left) and trace elements, including Th and U (right).
To collect this spectrum, an XFlash® SDD detector was used (P2 Con-X 02 analyzer modification). Its excellent energy resolution and throughput significantly increases the signal-to-noise ratio at fixed measurement time. In its turn, this increases sensitivity to the trace elements, including uranium.

3. Analysis of uranium as a minor element

Normally, uranium ores, even before beneficiation contain much higher amount of U, typically at least 0.1%, or 1 000 ppm. Measurement of U concentration with the P2 Con-X analyzer in this case becomes both faster and more accurate.

For example, in monazite ores, uranium content is typically about 0.2%, but amount of thorium may reach up to 4-7%. An XRF spectrum of such monazite ore is shown on the Fig. 3.

[Image: XRF spectrum of a monazite ore sample.]

In this measurement, a Si(Li) detector was used (P2 Con-X 01 modification) to enhance high-energy detection efficiency needed for analysis of rare-earth elements (La, Ce, Pr, Nd, etc.) using their K-series lines.

Despite inferior energy resolution of the Si(Li) detectors, the uranium XRF lines are clearly visible besides much stronger Th lines. Their partial overlap does not affect significantly the analysis precision thanks to use of a spectral deconvolution algorithm in the software.

Despite presence of strong neighboring Th lines, high quality of the analysis is reached. The U measurement precision is about 150 ppm (on 2σ level) and the detection limit is about 200 ppm.

4. Analysis of uranium from associated minerals

Often, uranium content is correlated to amount of other minerals that occur in higher amounts, or are easier to detect with XRF method. In different ore bodies, these may be minerals of Pb, Mo, Cu, Co, Ni, Bi, Sn, Ag and other elements.

Then a faster analysis may be performed using X-ray signatures of these associated minerals. In some cases, the semi-quantitative analysis time may be as low as 10-100 ms, allowing ore separation before leaching, secondary crushing or even before ore transportation from the mine. This greatly reduces expenses needed for ore chemical treatment and transportation.

However, one should keep in mind that XRF is effectively a surface technique and probes only up to 1 mm inside the material. Therefore mechanical material separation will be effective only if the ore lumps are more or less chemically homogeneous.
5. Analysis of uranium as the major element

Determination of uranium concentration with the P2 Con-X system is possible also in a concentrated product. In this case, U concentration may be determined both from strength of its XRF spectral lines (Fig.4), and from intensities of the main admixture element spectral lines. Combination of both methods, implemented in the P2 Con-X software, allows reaching the best accuracy, that is typically below 1% relative.

![XRF spectrum of a pure uranium oxide.](image)

**FIG. 4. XRF spectrum of a pure uranium oxide.**

6. Conclusions

The on-line X-ray fluorescence analyzer P2 Con-X is able to determine uranium content in various ores and materials. Quantitative and semi-quantitative analysis is possible from 100 ppm level up to 80% of uranium and more.

When uranium is present in concentrations below about 1%, its detection limit in 5 minutes of measurement time is about 60-200 ppm even in the worst cases (presence of strong neighboring Th XRF lines). Precision of its content determination in the same conditions is about 50-150 ppm.

When uranium concentration is higher, relative precision of its content determination decreases. It becomes better than 1% (relative) in the concentrated product.

On-line determination of uranium content with P2 Con-X analyzer provides fast and reliable results, thus helping to optimize the separation and concentration processes and cut down the end product costs.

REFERENCES


Elaboration of uranium ore concentrate by direct precipitation

A. Becis, H. Guettaf, K. Ferhat, T. Semaoune, K. Hanou, F. Ferrad, K. Yacoubi

Research Department of Chemical Process, CRND, COMENA, Algiers, Algeria.

Abstract. The production of a uranium ore concentrate (yellow cake) is an essential stage in the preparation of fuels used in the nuclear power reactor. In this work, we have studied the elaboration of a uranium ore concentrate from the ore of Tahaggart by testing the direct precipitation process. This choice was justified not only by the physicochemical characteristics of the ore, but also by other important factors such as: capacity of the deposit, geographical situation (desert), availability of water and lowest investment. Samples of uranium ore from Tahaggart, were crushed and leached by percolation with a diluted sulphuric acid solution to solubilize uranium. A rate of 95% was reached. The experiments were carried out with sample extracted from different locations in the deposit. The results indicate that the classical direct precipitation process is still valid only for 5% of the samples. For the majority of samples treated, we noticed that by precipitation of uranium at very low pH, one precipitation step was sufficient to obtain a concentrate of 65% of $\text{U}_3\text{O}_8$. The concentrate obtained is easily soluble in nitric acid. The chemical characteristics of the ore allow us to produce a concentrate using a process simpler than the classical double precipitation process.

1. Introduction

Uranium is a metal so reactive that it is found in nature under a multitude of mineral associations [1][2][3]. The ore of Tahaggart is characterized by the exclusive presence of secondary uranium minerals. The various spectral analyses and microscopic observations allow the identification of phosphate minerals: autunite $\text{Ca(UO}_2\text{)}_2\text{PO}_4\cdot10\cdot\text{H}_2\text{O}$ and torbernite $\text{Cu(UO}_2\text{)}_2(\text{PO}_4\text{)}_2\cdot10\cdot\text{H}_2\text{O}$ [4]

Several processes of treatment were tested to extract uranium from the ore of Tahaggart [5]. These processes considered a certain number of physicochemical parameters such as the nature of the mineral species, the reagents used and their concentration, the size of particles, and particular conditions of mining in Hoggar, particularly the constraints imposed by the distance, the scarcity of water and the lack of qualified local labour.

- The ore of Tahaggart is a deposit of low capacity. It is located in an isolated arid area.
- The direct precipitation process is suitable for such ores [6], because they satisfy or approach the following conditions:
  - A high uranium concentration of the leaching solutions.
  - Ore reserves are too low to justify investments for the installation of ion exchange or solvent extraction units.
  - The final product sufficiently satisfies the specifications without significant penalties due to the impurities.
  - The objective of our study is to evaluate the direct precipitation flowsheet in order to produce a uranium concentrate from Tahaggart ore.
1.1. The classical direct precipitation flowsheet

This flowsheet is composed by the following operations (Fig. 1).

**FIG. 1. Classical direct precipitation flow sheet.**

Five percent of the sample collected, after the sulphuric acid percolation, provide a uranium solution which can be treated by this classical flow sheet. The content of the uranium concentrate obtained was $[\text{U}] = 40\%$.

Figures 2 and 3 show the iron cake and the uranium ore concentrate obtained at laboratory scale by the classical direct precipitation flow sheet. The concentration of uranium in the iron cake is 5 % and in the concentrate is 40%.
1.2. The direct precipitation flow sheet with only one precipitation step

Ninety-five percent of the uranium ore sample cannot be processed using the classical flow sheet because in the first precipitation step at pH = 1.8, precipitation of a uranium concentrate occurs. For these samples, we applied the following one step precipitation flow sheet (Fig 4).
2. Experimental

2.1. Physical treatment

The ore was crushed at a particle size up to 0.8 mm.

2.2. Chemical treatment

Percolation leaching

- Weight of the ore in the column: 77 kg
- Ore size: \( d < 80 \text{ mm} \)
- Percolation agent \([\text{H}_2\text{SO}_4]\): 50g/l
- Percolation mode: Discontinuous
- Mode of sprinkling: Siphoning
- Duration of sprinkling: 173 hours (~ 8 days)
- Duration of drying: 34 days

Characteristics of the leaching solution

- \( \text{Eh} = 540 \text{ mV} \)
- Uranium concentration : 13.5g/l
- Iron concentration: 2.85g/l
- Sulphate concentration: 49.13g/l
- pH: 1.1, \( T = 27.3^\circ\text{C} \)

Leaching solution processed by batch of 5 litters
Precipitation parameters

Precipitant agent: Ammonia 28% R.P Normalized pure Prolabo
Ammonia flow rate: 0.48 ml/min with peristaltic pump
Agitation speed of the Pulp: 500 rpm /min
Agitator: Standard agitator anchors in Teflon

3. Results and discussions

3.1. Leaching

The uranium contents in the treated ore and the residue of leaching are summarized in Table 1.

Table 1. Uranium concentration in the ore treated and the leaching residue

<table>
<thead>
<tr>
<th>Nature of the sample</th>
<th>Uranium content* (%)</th>
<th>Uranium content** (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uranium ore</td>
<td>0.6</td>
<td>0.63</td>
</tr>
<tr>
<td>Sterile</td>
<td>0.027</td>
<td>0.028</td>
</tr>
</tbody>
</table>

* Analysis by the delayed neutron counting method (DNC)
** Analysis by volumetry

The operation of leaching on a pilot semi scale proceeded without major problems. The recovery of uranium extraction reaches 95%.

Figure 5 shows the evolution of the quantity of uranium extracted in each successive fraction of 2 litres.

"FIG. 5. Quantity of uranium extracted in each fraction."

The quantity of uranium is small at the beginning of the percolation. After the 5th fraction the quantity of extracted uranium increases considerably reaching a maximum of 46 g.

Figure 6 shows the recovery of uranium versus the liquid/solid ratio.
The recovery rate reaches 90% for L/S ratio of 0.5. The quantity of water used is very low.

FIG. 6. Variation of uranium recovery with liquid/solid ratio.

The initial pH of the leaching solution is about 1. When this solution flows through the ore bed, the acid is first consumed by alkaline compounds. This fact explains the pH increase in the first solutions. The breakthrough occurs for a pH value of about 1.4 (Fig 7).

3.2. Precipitation

In the classical direct precipitation flow sheet, the precipitation occurs in two steps. The first step occurs at pH = 3.5 to eliminate many impurities such as iron and aluminium and the second step at pH 7 that allows the precipitation of uranium. The concentration of uranium in the percolation solution is:
13.5 g/l. This concentration is convenient to apply the direct precipitation flow sheet. We noticed that when we add soda, lime or ammonia to the leaching solution produced, a precipitate occurs at a very low pH. This precipitate begins to appear at pH 1.4 and 99% of the uranium precipitates at pH 1.8. We also noted that when phosphorus is present in the leaching solution, it reacts with uranium at low pH to give a uranium phosphate compound such: U(HPO$_4$)$_2$.H$_2$O.

The analytical results of the uranium concentrate produced show effectively the presence of phosphorus (Table 2) (Fig 8).

Table 2. Analysis of uranium ore concentrate by XRF

<table>
<thead>
<tr>
<th>Element</th>
<th>Uranium concentrate produced</th>
<th>Standard uranium concentrate [3]</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>55%</td>
<td>55.11%</td>
</tr>
<tr>
<td>Fe</td>
<td>7.2%</td>
<td>1.0%</td>
</tr>
<tr>
<td>S</td>
<td>0.8%</td>
<td>1.1%</td>
</tr>
<tr>
<td>Ca</td>
<td>0.003%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Ti</td>
<td>0.38%</td>
<td>0.05%</td>
</tr>
<tr>
<td>Si</td>
<td>0.04%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Al</td>
<td>0.15%</td>
<td>—</td>
</tr>
<tr>
<td>P</td>
<td>8%</td>
<td>0.15%</td>
</tr>
</tbody>
</table>

*FIG. 8. Uranium ore concentrate produced by one step direct precipitation flow sheet.*

4. Conclusions

Leaching percolation of Tahaggart ore is efficient. We obtained a good recovery rate of uranium without addition of oxidant and at very low L/S ratio. The unit operation of conventional filtration is not necessary. The leaching solution flows through the ore bed and are recovered as clear pregnant solution. The ore bed presents a good permeability. The one step direct precipitation flow sheet is simpler than the classical direct precipitation process. It minimizes plant footprint.

The advantage in the case of Tahaggart ore is the possibility to obtain a concentrate titrating 65% U$_3$O$_8$, using only one concentration-purification operation. This concentrate is easy to dissolve by diluted nitric acid. Preliminary purification tests are positive.

REFERENCES


Phosphoric ore treatment by roasting it with sodium carbonate and leaching it with ammonium citrate for the recovery of soluble phosphate and uranium

E. de la Torre, A. Guevara
National Polytechnic University, Chemical Engineering and Agro industry Faculty, Extractive Metallurgy Department, Quito, Ecuador

E-mail address of main author: ernesto.delatorre@epn.edu.ec

Abstract. By thermal treatment of phosphoric ore, with low phosphorus contents and iron, aluminum, and silicon impurities, basic fertilizers with $P_2O_5$ soluble in citric acid or ammonium citrate, can be produced. The phosphoric ore lightly grinded with alkaline salts like $CO_3^{2-}$ and $SiO_2$ is roasted between 800 to 1000°C in rotary kilns. The roasted material contains from 25–30% of alkaline phosphates soluble in citrates. Phosphoric ore from the province of Napo-Ecuador with 24% of $P_2O_5$, 40% CaO in form of apatite, 20% of $SiO_2$ and 7 g/ton U is tested by thermic differential analysis, roasting at 800°C for 2 hours with 50% w/w of sodium carbonate and 2% w/w of $SiO_2$ by using a Nichols pilot furnace with 15 L of capacity which uses gas (propane-butane) as fuel, and agitated leaching with ammonium citrate (5% w/w). The initial ore and products are characterized by using atomic absorption spectrophotometry (Perkin Elmer AA400) and x-ray diffraction (Bruker D8 Advance). In the best conditions, 32% of phosphorus soluble in water is obtained as well as 40% of phosphorus and 56% uranium soluble in ammonium citrate.

1. Introduction

Pyrogenic treatment of the raw phosphate fertilizers permits the manufacture of basic $P_2O_5$ soluble in citric acid or ammonium citrate. These procedures deserve great interest because they permit the processing of raw phosphate with low concentration of phosphorus, as well as those containing iron and alumina, or with high levels of silicic acid impurities, which constitute the main part of the phosphatic minerals.

Several researchers such as Wiborg, Kraut, Knoop, Wolters [1] have proposed the production of alkaline phosphates and lime soluble in ammonium citrate, by the use of rotary kilns. However, the industrial practice of these procedures was not efficient due to the highly corrosive action of the masses of phosphates which can corrode almost any furnace material.

The industrial production of phosphates of alkali and lime, using rotary kiln, was not achieved until Messerschmitt, [1][2] found the conditions under which it was possible to agglutinate tri-calcium phosphate, lime and alkali silicates. This process has to deal with a complicated balance between the two fire-resistant acids $P_2O_5$ and $SiO_2$ on the one hand, and, on the other hand, between the alkaline and alkali non soil bases, resulting in the formation of an alkaline phosphate $P_2O_5(CaO)\alpha Na\beta O$ with calcium silicates and aluminum silicates.

The pyrogenic treatment reactions in combination with alkaline core can be represented by the following equations:

- phosphate ore with soda or caustic potash

$$P_2O_5(CaO)\alpha + CO_3Na_\beta \rightarrow P_2O_5(CaO)\alpha Na\beta O + CaO + CO_2$$
• phosphate ore with alkali silicate

\[
P_2O_5(CaO)_8 + SiO_2 \cdot Na_2O \rightarrow P_2O_5(CaO)_2Na_2O + SiO_2 \cdot CaO
\]

• phosphate ore with leucite

\[
P_2O_5(CaO)_8 + (SiO_2)_4 \cdot K_2O \cdot Al_2O_3 + 4 CO_3Ca \rightarrow P_2O_5(CaO)_2K_2O + 4 SiO_2 \cdot CaO + Al_2O_3 \cdot CaO + 4 CO_2
\]

Raw phosphate ore is finely grinded and then, by the addition of alkaline salts and sometimes some SiO_2, are mixed in special blend facilities. The “raw powder” is calcinated at a temperature of 800 to 1000°C in tabular rotary kiln. By this method, the transformation of the insoluble tri calcium phosphate in an alkaline phosphate of lime is proved. The alkaline phosphate of lime is the bearer of phosphoric acid [1][2][3][4].

The mixture, that in the roasting furnace has been agglutinated, is in the form of a porous material called “clinca”. This material is transferred to great refrigerating drums for final grinding. The obtained phosphate is a very fine, gray powder which spreads easily and which contains 25-30% phosphoric acid-soluble citrates [4][5].

2. Experimental Methodology

Phosphate ore from the province of Napo - Ecuador is tested, by differential thermal analysis and different roasting times and temperatures, with the addition of 50% w/w of sodium carbonate, and 2% w/w SiO_2, in a Nichols pilot furnace heated by gas (propane-butane), and agitated leaching with ammonium citrate, 5% w/w. The initial material and the final products are characterized by atomic absorption spectrophotometry (Perkin Elmer AA400) and x-ray diffraction (Bruker D8 Advance) [6][7][8][9].

The methodology used considers experimental stages working at laboratory and pilot scale, all this, trying to establish operational criteria and control for the investigated processes. The tests were conducted at laboratory scale in flasks with fixed bed of material (5 to 8 g) and in pilot scale with a furnace hearth mono Nichols, who reproduce the operating conditions of the multi hearth furnace stack.

Nichols mono hearth furnace uses liquefied petroleum gas (LPG) and can operate in fixed bed or stirred bed material with 15 liters of material and controlled air based in the \( \lambda \) lambda factor, which establish the relationship between air fed to the burner and the air required for complete combustion of liquefied petroleum gas. Therefore \( \lambda>1 \) involves an operation in oxidating atmosphere, and \( 0.4<\lambda<1 \) corresponds to an operation in reducing atmosphere. The composition of combustion gases from the furnace as a function of \( \lambda \) for propane (C_3H_8) to 0.72 atm. (atmospheric pressure in Quito) is shown in Fig. 1. The furnace design allows systematic sampling in order to assess the kinetics of the tested processes. Figure 2 shows a panoramic view of the furnace.
FIG. 1. Composition of combustion of propane (C₃H₈) to 0.72 atm.

3. Results and discussion

The results (Table 1) of the chemical and mineralogical analysis of phosphate ore samples from the province of Napo - Ecuador, are the following:
Table 1. Chemical analysis

<table>
<thead>
<tr>
<th>Element</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu (%)</td>
<td>0.03</td>
</tr>
<tr>
<td>Al (%)</td>
<td>0.43</td>
</tr>
<tr>
<td>Fe (%)</td>
<td>0.18</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>1.94</td>
</tr>
<tr>
<td>Mg (%)</td>
<td>0.02</td>
</tr>
<tr>
<td>K (%)</td>
<td>0.82</td>
</tr>
<tr>
<td>P (%)</td>
<td>10.3</td>
</tr>
<tr>
<td>As (g/Ton)</td>
<td>79</td>
</tr>
<tr>
<td>U (g/Ton)</td>
<td>7</td>
</tr>
<tr>
<td>P2O5 (%)</td>
<td>24.2</td>
</tr>
<tr>
<td>SiO2 (%)</td>
<td>20.6</td>
</tr>
<tr>
<td>Al2O3 (%)</td>
<td>1.8</td>
</tr>
<tr>
<td>Fe2O3 (%)</td>
<td>1.1</td>
</tr>
<tr>
<td>CaO (%)</td>
<td>39.9</td>
</tr>
<tr>
<td>MgO (%)</td>
<td>0.2</td>
</tr>
</tbody>
</table>

The phosphate ore samples have 24% P₂O₅, 40% CaO like apatite, 20% SiO₂ like quartz, and 7 g/ton Uranium; real density = 2.8 g/cm³ and pH = 9.0 (for a 2% solids pulp).

The differential thermic analysis results between 20 y 900°C (Table 2) show that the more important enthalpy variations are around 170 a 220°C.

Table 2. Differential thermic analysis results

<table>
<thead>
<tr>
<th>Temperature range</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 – 50</td>
<td>Exothermal peak, low intensity</td>
</tr>
<tr>
<td>170 – 220</td>
<td>Endothermal peak, high intensity</td>
</tr>
<tr>
<td>420 – 460</td>
<td>Exothermal peak, medium intensity</td>
</tr>
<tr>
<td>460 – 500</td>
<td>Exothermal peak, medium intensity</td>
</tr>
<tr>
<td>700 – 720</td>
<td>Exothermal peak, low intensity</td>
</tr>
<tr>
<td>720 – 750</td>
<td>Exothermal peak, low intensity</td>
</tr>
</tbody>
</table>

FIG. 3. Recovery of phosphorus in solution.
In Figure 3, the results of tests to determine the variation of the solubility of phosphorus leaching in water and ammonium citrate samples previously calcined for 2 hours at 200, 400, 600, 800, 900°C are shown.

It can be seen that when the sample is calcined at 200°C, the percentage of recovery of phosphorus in solution decreases significantly from the value obtained for the original sample (without calcinations), both for leaching in water and in ammonium citrate. From 400°C this value increases slightly, but for the leaching in water it is always lower than the value of the original sample. In the case of leaching in ammonium citrate, when the sample is calcined at 800°C and 900°C, higher values are obtained compared with the original sample; however the increase is not quite significant.

The use of sodium carbonate in the roasting, as shown in Figure 4, promotes the solubility of phosphorus and uranium in a solution of ammonium citrate. When operating under the best conditions, recoveries of 32% water soluble phosphorus and 40% phosphorus and 56% of soluble uranium in ammonium citrate can be obtained.

The results presented in Fig. 5, show that the addition of silica in form of sodium silicate increases the solubility of phosphorus to 43% when the samples of phosphoric ore are roasted with sodium carbonate.
FIG. 5. Recovery of phosphorus, in solution, calcined sample at 800°C, 2 h.

4. Conclusions

- The samples of phosphoric ore from the province of Napo - Ecuador, with contents of 24% $P_2O_5$, 40% CaO, as apatite, 20% SiO$_2$ and quartz, and 7 g / ton U, treated by roasting, with the addition of 40 g sodium carbonate, 3 g silica and 30 g of sample, and then calcined at 800°C for 2h., can achieve a recovery of 40% of phosphorus and 56% of soluble uranium in ammonium citrate.

- Tests of direct calcinations of the samples are not justified due to the low solubility of phosphorus obtained. Nevertheless, tests on the fluxes of sodium carbonate, potassium carbonate and silica present an interesting alternative to establish the behavior of the material with furnaces with direct flame in order to obtain sufficient quantities of product to be tested in agricultural application.

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REFERENCES


Optimization of technological processes at uranium ore mining and milling in Ukraine

O.G. Sorokin\textsuperscript{a}, V.V. Sinchuk\textsuperscript{a}, S.O. Bezrodnyi\textsuperscript{a}, I.I. Koshyk\textsuperscript{b}

\textsuperscript{a}State Enterprise "Eastern Ore Dressing Complex" (VostGOK), Zholtieh Vody, Ukraine

\textsuperscript{b}State Enterprise "Ukrainian R&D Institute for Industrial Technology", Zholtieh Vody, Ukraine

\textit{E-mail address of main author: sorokin@zhv.dp.ukrtel.net}

\textbf{Abstract.} Uranium industry of Ukraine is 60 years old. It partly satisfies needs of Ukrainian NPPs; however, the raw materials base of the uranium industry in Ukraine allows covering the requirements of the NPPs fully. The raw materials base has special features comparatively with other countries of the world. The industrial uranium resources of Ukraine are large-scale but the ores, as a whole, are related to low-grade ones by uranium content. The main industrial type of uranium deposits in Ukraine is metasomatite and the ores occur as hard rocks. Monometallic nature of the ores stipulates possibility of high-quality uranium concentrate output with very low content of detrimental impurities. Mining and processing technologies are different from the foreign ones. The Ukrainian government approved a number of programs aimed at increasing uranium production up to the level, which can satisfy the requirements of the nuclear power plants, modernization of technology (heap leaching, in situ leaching, in-place leaching) and also liquidation of negative environmental consequences of uranium mining and processing activities.

\section{Description of uranium industry in Ukraine}

Uranium has been produced for more than 60 years in Ukraine, so Ukraine is in the top ten of the largest uranium mining countries; it also ranks ninth or tenth in the world in the quantity of nuclear power units and their capacities. The first unit was put into operation in 1977. Nuclear energy is one of the major industries in Ukraine; the electricity generated in NPPs amounts to more than 50\% in the energy mix of the country. By this index, Ukraine ranks fifth in the world.

The recoverable reasonably assured resources of uranium in Ukraine can meet the requirements of the NPPs for more than 100 years, even taking into account the nuclear energy development.

Uranium is presently produced in Ukraine by underground mining method; in 1960–80s, uranium was mined by in situ leaching.

Currently, there is the single uranium mining enterprise in Ukraine: the State Enterprise "Eastern Ore Dressing Complex" (VostGOK). In addition, a new uranium mining center is being built at the Novokonstantinovskoyeh deposit; in situ leaching mine project at the Safonovskoyeh deposit is being developed.

Research and development support of technological processes in uranium industry is provided by a number of designing and research institutes and centers.
2. **Short historical review on uranium mining and milling in Ukraine**

Uranium ore mining in Ukraine began in 1948 at the Pervomayskoyeh deposit. In 1951, the Eastern Ore Dressing Complex was created to develop the Pervomayskoyeh and Zheltorechenskoyeh uranium deposits.

For milling of the mined uranium ore and uranium material from the countries of Eastern Europe a processing plant in Dnieprodzerzhinsk city was put into operation in 1949. The capacity of the plant amounted to 5,000 tonnes of uranium per annum. In 1959, the second plant for uranium ore milling was built in Ukraine in Zholtiyeh Vody town.

In 1960-70s, uranium mining moved to Kirovograd region. Development of the Michurinskoyeh, Vatutinskoyeh and Tsentral’noyeh uranium deposits began there and are currently operating.

In 1989, as conversion began in the USSR, the work on uranium mining by in situ leaching was suspended, as well as the work on commercial development of the Novokonstantinovskoyeh and Severinskoyeh deposits. In 2004, construction of the uranium mining center at the Novokonstantinovskoyeh deposit was recommenced.

For the whole period since 1948, about 125 thousand tons of uranium has been produced as U₃O₈ in Ukraine including 65 thousands tons – from domestic ores (see Fig. 1).

![FIG. 1. Uranium production in Ukraine.](image)

3. **Plans for development of uranium industry in Ukraine**

The Energy Strategy of Ukraine through the year 2030 assumes 8 times increase in uranium mining output. For that, the following is planned:
- development of the operated mining facilities at VostGOK;
- putting into operation of uranium mining enterprises on the basis of five deposits to be mined by underground method;
- putting into operation of uranium mining enterprises on the basis of five deposits to be mined by in situ leaching;
- reconstruction and expansion of the hydrometallurgical plant operated currently;
- expansion of the volume of the tailings storage pond of the hydrometallurgical plant;
- construction of a new milling complex at the Novokonstantinovskoyeh deposit.

4. Features of raw materials base of uranium industry in Ukraine

The main industrial type of uranium deposits in Ukraine is metasomatite: 98% of the total resources. Sandstone deposits make up 2% of the resources. Thus, the strategy of the uranium industry development in Ukraine is built on uranium mining of the metasomatite deposits; the sandstone deposits are expected to play an auxiliary role.

All the industrial deposits of metasomatite type are concentrated on the territory measuring 80 by 20 km within Kirovograd region.

The ore is delivered to the milling plant by railway at a distance of to 100-300 km from the operated mines.

Layout of uranium industry's facilities in Ukraine is shown in Fig. 2.

![FIG. 2. Layout of uranium industry's facilities in Ukraine.](image)
The industrial uranium deposits of Ukraine are large-scale by uranium reserves that allow creating high-capacity mining enterprises. The low boundary of the industrial ores is set at a depth of up to 1,300 m. It stipulates the possibility of their mining by exceptionally underground method – far more expensive than open-pit method.

The ores, as a whole, are low-grade; the content of uranium varies near 0.1%; it increases up to 1% on individual local areas. It should be noted that nowhere else in the world, such low-grade ores are mined by underground method.

Geological sections at Severinskoyeh and Vatutinskoyeh deposits are shown in Fig. 3.

High dilution reaching 30% when the ore is mined is stipulated by large quantity of waste rock spots within the ore contour.

Considerable differentiation of the ore beds by thickness (it varies from 2 to 100 m) calls for using different mining methods – high-performance methods with mass ore breaking for thick ore beds and selective mining methods for low-thick shallow ore beds.

The ores occur as hard rocks that call for drilling-and-blasting operations for drifting and ore breaking. At the same time, it allows drifting without support and creating considerable outcrop areas when the ore is broken.

The day surface of Ukrainian uranium deposits, as a rule, is presented by valuable fertile black earth, occasionally – by urban areas. It results in a number of requirements to mining methods: deformation of the earth surface must be prevented and seismic load of drilling-and-blasting operations on the surface buildings must be minimized.

As contents of uranium and other components are increased, the mine water can not be discharged into the drainage network and must be cleaned.

Low content of uranium, weak emanation ability of the ores make it possible to provide normal hygiene-and-sanitary labour conditions for the mine personnel by arrangement of sufficient ventilation.

Ore mineralization occurs, mainly, as uraninite, pitchblende and brannerite.
Uranium minerals are dissipated in the ore mass and have ultrafine sizes: nearly 90% of uranium is concentrated in grains sizing less than 70 µm. As a result, the hydrometallurgical processing of the whole mined ore is required instead of conventional physical methods.

Monometallic nature of the ores stipulates possibility of high-quality uranium concentrate output with very low content of detrimental impurities.

By radiometric dressability, the ores are related to weakly- and medium-contrasting that requires the perfect process flowsheet of radiometric concentration.

The deposits are located in the well developed region, with the developed traffic network, arranged power supply systems, favourable climate and high supply of labour.

5. Description of the operated technological process of uranium ore mining and milling

The technological process of uranium ore mining and milling in Ukraine consists of the following basic operations:

- Ore mining by underground method – sublevel drifts (crossdrifts) with backfilling worked-out mine voids using solid backfill
- Ore crushing and screening at a mine
- Radiometric separation of +40 mm size
- Piling of tailings from the radiometric separation
- Ore milling at the plant with production of oxide uranium concentrate containing 84% of natural uranium. The process of the ore milling is different from the foreign technologies. The full capacity of the plant is 1800 tonnes of uranium annually as UOC (90%UO₂; 10%UO₃).
- Ore grinding to 95% of -0.25 mm
- Sulfuric acid leaching
- Sorption from the pulp to anionite
- Sulfuric acid desorption
- Extraction and re-extraction
- Drying and calcination
- Storing of the end product

6. Basic areas of optimization of technological processes

The analysis of the operated flowsheet of uranium ore mining and milling in Ukraine reveals the number of problems which require optimization of the whole process.

The first problem is use of out-of-date domestic equipment in the mining production that once or twice yields to the up-to-date equipment from leading world producers by efficiency and hygiene-and-sanitary characteristics. Its use leads to high dilution.
The second problem is availability of considerable volume of ore fines (-40 mm size) which presently can not be exposed to radiometric separation and are shipped directly to the plant, sharply reducing the grade in the end ore product.

The third problem is an out-of-date power-consuming flowsheet at the hydrometallurgical plant.

Thus, a new flowsheet and basic areas of optimization of the technological processes are developed:

- Technical re-equipment of the production (Slide 20). Through the year 2012, it is planned to purchase 25 mining production units and 41 milling production units.
- Application of the optimal mining methods taking into account the specific mining and geological conditions of the mined beds and economics of the production.
- Control of the grain-size distribution of broken ore to diminish the output of ore fines and to increase the efficiency of separation. It is to be achieved by increase in accuracy of blasthole drilling and more exact calculation of drilling-and-blasting parameters.
- Radiometric separation advancement by development of multi-stage separators with automatic adjustment of separation thresholds depending on properties of delivered ore.
- Construction of underground radiometric separation plants with tailings utilization as a constituent of combined backfill for backfilling worked-out mine voids of exhausted blocks that will allow increase in capacities of available ore hoists.
- Construction of heap leaching plots on the sites of mines to carry out sulfuric acid leaching of ore fines, as well as of radiometric separation end product crushed to -10 mm. The processed material will be in the volume enabling its placing, after leaching and neutralization, completely as a constituent of solid backfill to backfill worked-out mine voids of exhausted blocks.
- Application of sulfuric acid in situ leaching to low-grade ores with creation of artificial permeability of ore massif by drilling-and-blasting.
- Reducing the cost of natural uranium concentrate production, the operation of sandstone deposits by acid in situ leaching is planned to begin through two years.
- The hydrometallurgical plant reconstruction to produce uranium oxide concentrate of nuclear quality for its direct conversion into uranium hexafluoride, as well as expansion of the effective volume of the operated tailings storage pond.

The new flowsheet of uranium ore mining and milling processes in Ukraine is shown in Fig. 4.
7. Utilization of solid wastes from mining production

To improve the environmental condition and mitigate radiation exposure on the environment and public, works on diminishing volumes and activity of mining wastes were started in the region of uranium mining.

For this purpose, mobile complex of radiometric separation was developed, manufactured and mounted at the Smolinskaya mine (see Fig. 5).

Up-to-date separators allowing to separate a low-grade ore concentrate from piles, clean tailings and the end product with uranium content of 0.06 to 0.011%, were installed at the complex.

The radiation load on the environment has been 17% reduced.

It is planned to build the same complex at the Ingul'skaya mine in 2010.

FIG. 4. New process flowsheet.
8. Conclusions

- The raw materials base of uranium industry in Ukraine requires unconventional engineering solutions to develop optimal flowsheet of ore mining and milling.

- Implementation of research and experimental-industrial efforts by VostGOK makes it possible to create complex mining-and-chemical technology of economically efficient mining of low-grade uranium ore in Ukraine.

- Taking into account the growing interest to uranium mining at low-grade deposits throughout the world, the approaches developed in Ukraine can be used in other countries where low-grade uranium deposits are available.
Legal aspects related to the phases of decommissioning, operation, and construction of uranium mines in Brazil owned by Indústrias Nucleares do Brasil - INB

A.C. Barreto, E.M.L. Batalha, A.D.L. Mayerhoff
Indústrias Nucleares do Brasil, city, Brazil

E-mail address of main author: alessandra@inb.gov.br

Abstract. Indústrias Nucleares do Brasil – INB is a Brazilian company active in the states of Minas Gerais, Bahia, Ceará, through its uranium mining and milling plants, each in a different phase of licensing. The Caldas facility in Minas Gerais is the first uranium mine to be decommissioned. The Caetité facility in Bahia is in operation and INB is currently seeking to license the changed mining method from open pit to underground mining, the first ever in Brazil. The Santa Quitéria Project, in the implementation phase, is also unique because the deposit is characterized by the presence of uranium associated with phosphate, and its economic feasibility is contingent upon the exploitation of the associated phosphate. The licensing conduct and requirements for these plants are the subject of a study and work, by both the project owner and the regulatory bodies. But in the presented cases, the licensing process has not shown to be sufficient to prevent questions about the project by the affected community. Facts occurred in connection with INB have evidenced the necessity for significant investment to be made in environmental education and for conducting an important work on risk perception and communication, so as to facilitate integrating the project owner with the neighboring community.

1. Introduction

Uranium mining and milling plants in Brazil are licensed by the National Nuclear Energy Commission (CNEN) and by Environment and Natural Renewable Resources (IBAMA). The licensing procedure conducted by CNEN involves all steps of the project: from its setting out after site authorization, through construction, operation and decommissioning. The entire process is governed by specific rules for nuclear facilities dealing with each of these phases.

In parallel, IBAMA’s environmental licensing procedure comprises the granting of the following licenses: Prior License awarded during the planning phase of the project; Installation License authorizing construction on basis of the approved detailed design; and Operating License authorizing the start of the licensed activity and the operation of pollution control equipment.

In the course of the licensing procedure, a number of documents are requested by the environmental agency, the most important ones being:

- Environmental Impact Study (EIS) and the corresponding Environmental Impact Report (EIR) at the setting out of the project;
- Detailed design at the installation of the project;
- Detailing of environmental programs with project operation;
- Plan of Rehabilitation Degraded Area, at project decommissioning.
This paper is intended to present the uranium mining and milling facilities run by Brazil, the licensing step they are in, their pioneering role in this country, and the project owner’s difficulties in managing the licensing process issues and the technical challenges according to scientific, legal, social, environmental, political, and economical viewpoints.

With the resumption of the Brazilian Nuclear Program, an increase is planned in the domestic production of uranium concentrate with new projects under construction and in operation. This entails the need to conduct environmental remediation activities simultaneously with the operation of the mine and to acquire know-how for decommissioning the facility at the end of its useful life. Also, it will be necessary to build up solid competence to cope with the demands and difficulties of a technical, scientific and legal nature existing not only in the setting up, operation, and decommissioning of the facilities, but also in connection with public acceptance of the nuclear activity.

2. Description of the industrial mining projects of Indústrias Nucleares do Brasil

2.1. Caldas facility – Minas Gerais

The former Poços de Caldas Industrial Complex – CIPC belonging to Indústrias Nucleares do Brasil is located in the city of Caldas/ Minas Gerais and was the first Brazilian facility to produce uranium in industrial scale (Fig 1). It started producing uranium concentrate (yellow cake) in 1982 and was temporarily closed in 1997.

Currently known as Ore Treatment Plant, the facility is in an area of 3.2 thousand hectares and has a 2 km diameter open pit; in addition to 108 million tonnes of mining overburden and 2.4 million tonnes of tailings from the ore treatment plant. It involves a constructed area of 30 thousand square meters, where equipment used in the past for uranium concentrate production is still present. Today, the facility has no production activity, and many of its employees have been transferred to the facility in operation, located in the state of Bahia.

Many of the activities now being carried out in the facility involve remediation of degraded areas, mainly heaps of overburden, drainage basins and storage places for industrial waste from uranium processing. The presence of sulfide ores, mainly pyrite (FeS₂), causes the formation of acid drainage from heaps and the consequent production of a large volume of water containing high concentrations of stable and radioactive isotopes. Continuously treating such waste throughout these years means a high cost for the company.
Anticipating the decommissioning of the facility, INB has been developing a series of mitigation measures, such as reducing the volume of acid drainage water. Because of the smaller volume of water to be treated, this has brought about significant savings of electric power and lime consumption, and has made possible a more effective operating control within the facility’s capacity limit.

2.2. **Caetité facility – Bahia**

To the southwest of Bahia, near the municipalities of Caetité and Lagoa Real, one of the most important uranium provinces of Brazil is located. The implementation of the Industrial Uranium Mining Complex, originally called Lagoa Real Project and currently titled Uranium Concentrate Plant – URA, was started in 1998 (Fig 2).

The commercial-scale operation started in 2002, when the extraction of uranium ore with an average content of approximately 2 900 ppm in equivalent U₃O₈ was started through an open-pit mine on the Cachoeira deposit. Mineral beneficiation in the industrial facilities comprises the following steps [1]: uranium extraction by heap leaching; concentration and purification by the counter-current solvent extraction method; and production of the corresponding concentrated ammonium diuranate (ADU). The current annual production of ADU is 400 metric tonnes of equivalent U₃O₈.

*FIG. 2. Caetité facility.*

Of the 35 deposits explored so far, the site selected for development was the Cachoeira deposit, which concentrates the highest average content – 3 500 ppm U₃O₈ geological. By applying economic parameters, the mine is an open-pit development project to the depth of 140 m so as to produce ore with an average content of 2 900 ppm recoverable U₃O₈ for beneficiation.

The next phase of the project, currently in the course of licensing, is the shift to underground mining for a better economic development of the ore site. It will be the first Brazilian uranium underground mine. INB’s planning of activities for the Lagoa Real uranium province includes the economic development of other deposits, in principle 3 among the 35 known deposits.

2.3. **Santa Quitéria facility – Ceará**

The Santa Quitéria Project, in the early implementation process, is located in the central region of the State of Ceará, about 45 km southeast of the city of Santa Quitéria. The deposit is characterized by the presence of uranium (reserves of the order of 80 thousand metric tonnes U₃O₈ associated with phosphate (reserves of the order of 9 million tonnes P₂O₅) and, although it is the largest uranium reserve existing in Brazil, its economic feasibility is contingent upon the exploitation of the associated phosphate [2] (Fig 3). The average contents found are 11% P₂O₅ and 0,1% U₃O₈. This means that
uranium extraction is conditioned on the production of phosphoric acid, the input used in the production of fertilizers and mineral salt. This fact determines unique particularities in the licensing process for that facility.

The project comprises open-pit mining, mineral beneficiation/processing for phosphoric acid, and further processing of phosphoric acid for production of fertilizers, mineral salt and uranium concentrate from uranium by-product in a separate plant.

The area containing the deposit is a very poor region, it being estimated that the project will represent a large positive impact on regional development from the generation of 3 000 jobs – direct, indirect and associated – with the attraction and settlement of people in the region.

3. Current licensing status of INB projects

3.1. Caldas facility – Minas Gerais

The closure of the CIPC mine, with the decommissioning of the facility and environmental remediation of degraded areas, will be pioneering in Brazil and will happen after implementation of the PRAD – Plan for Rehabilitation of Degraded Areas. The PRAD is part of the agreement entered into by INB and IBAMA and CNEN, the licensing and oversight agencies with jurisdiction over the company’s activities. This is called for in the overall plan for facility decommissioning, covering the closure and remediation approaches for the tailings ponds, mine pit, heaps of overburden and waste from uranium chemical processing, industrial areas and others.

Since 2004, when the regulatory body presented the Term of Reference, a number of factors hindered and delayed the hiring by INB of a company with the necessary technical qualification to prepare such document [3]. Three attempts were unsuccessful, and this year (2009) new contracting proceeding is under way. The main hindrances have to do with Brazil’s lack of practical experience and skills in uranium mine remediation and decommissioning, plus legal and bureaucratic difficulties for a government-owned company to hire service contractors, mainly with international organizations. The cost of preparation of the PRAD is in the order of 2 million dollars.

3.2. Caetité facility – Bahia

The uranium mine and mill site in Caetité, State of Bahia, has been in commercial operation since 2002. Its Initial Operating Authorization was granted by CNEN for renewable periods, the facility’s production being limited to 400 metric tonnes of uranium concentrate.
At present, the facility has an Operating License granted by IBAMA. The conditions for maintaining and renewing the facility’s environmental license are as follows: continue the proposed environmental programs and the mitigation measures indicated in the environmental studies and submit relevant annual progress reports. These include: Fauna and Flora Management and Conservation; Monitoring and Mitigation: Monitoring of Air Quality; Monitoring of Underground Water Quality; Biological Monitoring; Monitoring of Effluents and Wastes; Control of Solid Wastes; and Socioeconomic Aspects: Social Communication and Environmental Education.

Another demand of the license is an Epidemiological Study, in progress, on the possible occurrence of diseases related to genetic damage and malignant neoplasms in the area of influence of the URA.

The need to shift to underground from open-pit mining was already acknowledged in the project’s detailed design. Notwithstanding, a new license application was recently filed for the project with CNEN and IBAMA. Initially, only the construction of the access ramp was authorized. Under the environmental licensing procedure, IBAMA required INB to prepare an Environmental Study within the scope established by the regulatory body. This includes a description of the mining method; an explanation of the systems installed for environmental protection and control and occupational safety; reviews of Risk Analysis, Emergency Plan, Radiation Protection and Environmental Protection Plan; in addition to planning of actions for facility decommissioning.

In connection with nuclear licensing, the regulatory body required that a new socio-economic research within the project’s area of influence (15 km radius), be conducted 7 years after the previous one in order to update the information on the community’s land and water use patterns. Such research is nearing completion and, upon the opinion of the regulatory body, the review of the facility’s Safety Analysis Report will be started.

In addition, complying with the regulatory body’s requirement, INB is reformulating its Environmental Education Program in order to involve the neighboring community in the facility’s production activity through a participative approach that includes an evaluation of public acceptance of the project, and aspects related to risk communication, regional insertion, etc. The Environmental Education Program is expected to involve employees, family members and the community of municipalities within the unit’s area of influence.

### 3.3. **Santa Quitéria Project – Ceará**

The licensing history of the Santa Quitéria Project shows that it represents a particular case in this country. Since 2005, it has been a subject of study and discussion by INB - the project owner - the regulatory bodies CNEN and IBAMA, the environmental agency of the State of Ceará, where the deposit is located, in addition to the state and federal levels of the Judicial Power. The fact is that INB adopted the strategy of separating the project into two Units: a Phosphate Facility for production of phosphoric acid and fertilizers; and a Uranium Facility, responsible for the production of uranium concentrate. In this case, mining and mineral beneficiation activities belong to the Phosphate Facility.

INB chose to obtain the environmental license for the Phosphate Facility from the environmental agency of the State of Ceará, as established by the Brazilian legislation on mining activity in general. At the same time, INB started the environmental and nuclear processing of the Uranium Facility. In this case, the project being a nuclear facility for production of uranium concentrate is, by force of law, a monopoly of the federal government; accordingly, the licensing of its operations belongs to IBAMA and CNEN. The debate was then focused on the boundary of what would be a nuclear facility and, therefore, the subject of licensing by these federal agencies.

INB already has the official documentation from the parties involved in the process agreeing to the adopted licensing strategy; still, the company is not yet free from some challenges by those who oppose the chosen method.
Currently, the Phosphate Facility’s installation license from the State of Ceará is in the process of renewal, and the Uranium Unit is in possession of the Term of Reference prepared by the federal environmental agency IBAMA for the project’s Environmental Impact Study. CNEN, the nuclear regulatory body, has yet to issue a position on Site Approval, the first step of nuclear licensing.

It should be stressed that although the Environmental Impact Study refers to the Uranium Facility, it has a wide scope that covers the entire project because, as the federal environmental agency understands it, the environmental impact evaluation cannot be a fragmented effort.

On this project, for its particularities ensuing from the uranium-phosphate association, where phosphate is the preponderant element, and for the necessity of a partnership between INB and a private entity to make the project feasible, a longer delay is perceived in the steps to be completed under the administrative procedure of licensing.

4. Process difficulties and challenges: Decommissioning, operating and implementation of uranium mines

The former Poços de Caldas Industrial Complex – CIPC, located in Caldas/Minas Gerais, was built and started producing uranium concentrate (yellow cake) in 1982, prior to the enactment of environmental legislation in Brazil. Therefore, many of the currently popular environmental remediation techniques were not practiced at that time, and the environmental issue was left to be addressed at the end of the project’s useful life. Today, there is an environmental liability to be settled and a Rehabilitation Plan for Degraded Areas to be prepared as part of the actions for facility decommissioning. This country lacks practical experience in this area, because such facility is the first uranium mine to be decommissioned, and the challenges are many. The first one, from a technical viewpoint, given the characteristics of the environment, is that a number of studies, simulations, use of computational models are needed, which means time and cost for the project owner. A second challenge would be of a sociopolitical nature, with the need to have the stakeholders engaged in the process of defining and accepting the environmental remediation techniques.

In the case of the uranium mine in operation in the State of Bahia, Brazil, its uniqueness is highlighted today by the shift to underground mining, away from the open-pit method. Although underground mining operations exist in Brazil, this project will be the first ever underground uranium mine to operate in this country, and has, therefore, brought an even stricter control on the part of regulatory bodies for the granting of licenses. Since the start of commercial-scale operation of the Caetité/Bahia URA in 2002, with the open-pit mine and the mineral processing facility, INB has worked to meet all requirements of the regulatory bodies and satisfy all demands of the licenses. The company’s experience shows that this has not been sufficient. The URA adopts environmental remediation techniques and conducts rehabilitation of the area while still in operation, so that by the end of the project’s useful life the actions needed for decommissioning will be well planned and minimized. Notwithstanding, recent developments show that there are many difficulties to be overcome in the process, mainly in connection with the knowledge and understanding of the activity and its acceptance on the part of the project’s neighboring communities. In this connection, opponents of the nuclear industry, such as Greenpeace, the local Church and other opinion makers created and placed technically ungrounded news items in national network. This was widely explored by the media and caused damage to the company’s image until it was finally cleared up.

Finally, with respect to the uranium-phosphate mine being established in the State of Ceará, once the legal difficulties are overcome, the approach will draw on the experience and challenges faced in the course of the two other projects, one in operation, and the other being decommissioned. Thus, theoretically, some situations are prevented from happening, which means savings in material and human resources at the end of the process. From the viewpoint of a uranium mining and milling operation, we must anticipate ourselves; this means being conservative and conducting whatever studies are required, whether of a technical, socio-environmental, or political-economic nature, etc. At the same time, it is important to adopt relevant policies and get world recognized certifications for usual systems like Integrated Quality, Safety, Environmental Management, and Social Responsibility.
And, in fact, the current juncture has raised the interest of the industry as a whole for the so-called Social License.

5. Conclusion

The three presented cases of uranium mining and milling facilities in Brazil, namely the first in decommissioning, the second in operation, and the third in the implementation phase are unprecedented and pioneering situations in this country. This has entailed a greater effort by INB to meet the licensing requirements, with higher costs and longer time schedules.

INB has worked toward acquiring and expanding the knowledge necessary for the studies demanded by the regulator, by hiring consulting firms and promoting exchanges with international organizations and other companies of known experience in the related areas, besides training programs conducted locally or abroad, and technical visits.

Still, the licensing process for the facilities has not proven sufficient to prevent questions about the project by the community concerned. The facts happened to INB evidence the need for extensive investment in Environmental Education and an important work to be done in risk perception and communication. This is intended to facilitate integration of the project owner with the neighboring community and prevent the biased media exploration of ungrounded accusations by those who, for different reasons, come forward against the nuclear activity, and therefore work to mess up the process.

Social and Environmental responsibility actions with the parties concerned should be part of the project owner’s routine, regardless of the phase the project is in, and the ideal is that such efforts be worked on from a strategic and operational viewpoint. The Brazilian experience has shown that, in this context, mining is in the lead and the nuclear industry in Brazil is expected to follow this trend, given the setting favorable to the growth of its activities.

REFERENCES

Licensing process for a uranium ore mining and milling facilities located in the state of Bahia, Brazil

E.M.L. Batalha, A.C. Barreto, A.D.L. Mayerhoff

Indústrias Nucleares do Brasil S A. (INB), Rio de Janeiro; Brazil

E-mail address of main author: ebatalha@inb.gov.br

Abstract. The Uranium Concentrate Plant – URA – is a plant engaged in uranium ore research, mining and milling activities. The plant aims at producing natural uranium concentrate in the form of ammonium diuranate – ADU, used as raw material for fuel production for nuclear plants. This paper discusses the aspects related to nuclear installation licensing, featuring all steps of the process and emphasizing the requirements of control agencies. It also approaches the epidemiological study required by IBAMA during the process of environment licensing, in order to define possible influences of URA's activities on the neighboring population’s health.

1. Introduction

Brazilian legislation establishes that nuclear activities in Brazil be subject to an extensive, detailed licensing process, both from the nuclear viewpoint – with the National Nuclear Energy Commission (CNEN), and from the environmental viewpoint – with the Brazilian Institute for the Environment and Natural Renewable Resources (IBAMA), which evaluates the positive and negative impacts of such activities on workers, the public and the environment.

The licensing process consists of defined steps that are to be adhered to on pain of rendering any granted licenses invalid. By an analysis of the documents submitted in the course of the process, all possible impacts from the would-be licensed activities are evaluated. Not until the completion of all specified steps will licenses and permits be issued for the functioning of the facilities. As necessary, demands and requirements are established for adherence by the owner/operator, so as to minimize the negative impacts from the activities and thus provide a safe operation.

This paper will discuss the formalism of existing licensing procedures, with emphasis on the environmental licensing of a uranium mining and milling facility owned by Indústrias Nucleares do Brasil S.A.

2. Project description

Cachoeira farm, where the Cachoeira deposit (Deposit/Anomaly LR-13) is located, was the first rural property acquired by INB [1]. Originally called Lagoa Real Project – LRP, this is a mining industrial complex currently called Uranium Concentrate Plant – URA, located in the municipality of Caetité, State of Bahia, Northeast Brazil.

This project defines the opening and operation of an open-pit mine located on the Cachoeira deposit (Deposit/Anomaly LR-13), for extraction of uranium ore with an average content of approximately 2 900 ppm in equivalent U₃O₈, with milling operations being done in industrial facilities built for uranium extraction by acid heap leaching, concentration and purification by counter-current solvent extraction, and production of the respective concentrate in the form of ammonium diuranate (ADU).
The period of open-pit mining is estimated at approximately 12 years for an annual ADU production of 400 tonnes.

The Cachoeira Deposit was selected for initial operation for it presents the main geological and economical parameters (highest average content of geological uranium – 3 500 ppm, mineralized thickness, volume and morphology) more favorable for industrial use among the 35 deposits/anomalies surveyed to the present day in the region. The mine overburden and waste ore from the leaching piles are disposed of conjointly nearby the pit in a place adequately chosen aiming at minimum environmental impact.

![Image](image_url)

FIG. 1. URA- Uranium concentrate plant.

It is worth stressing that, at the time of project inception, a key aspect that led INB to start exploiting that region’s ore deposit was the low investment – in the order of US $23 million – needed to make the project feasible. In addition, the uranium is found in deposits that allow a modular exploitation method. INB is currently in the process of obtaining the relevant license for exploiting the same anomaly through underground mining.

Additional uranium resources can be found at the Lagoa Real Uranium Province, Constituted by 12 deposits, from which 7 of those have the surveys partially concluded, have evolved to the mineral deposit category. On the other side it is believed that the potentiality presented by the 23 uranium anomalies yet not evaluated through boring might add considerably to those resources

At present, as an extension program, the URA is establishing other projects for extraction (underground mining) and processing of uranium concentrate (dynamic leaching), while carrying on exploitation on the same deposit. Subsequently, plans contemplate the development of other deposits that make up the Lagoa Real Uranium Province.

The plant occupies an area of approximately 870 hectares, where the facilities of the complex are distributed, as shown in Fig. 1.

3. Licensing procedures

The items below describe the licensing procedure for a nuclear facility.
3.1. **Nuclear licensing**

Every nuclear facility in Brazil must undergo a licensing process with the National Nuclear Energy Commission-CNEN [2], whose guidelines are unique in dealing with radiological parameters. Their provisions include requirements on equipment design and size; civil engineering and industrial erection; systems and devices for industrial, radiation, and environmental safety, and property security of nuclear facilities.

The process is regulated by CNEN Rule NE 1.13 – Licensing of Uranium/Thorium Mining and Milling Facilities and the CNEN Rule NE-1.04 – Licensing of Nuclear Facilities, applicable to the activities associated with the siting, construction, and operation of nuclear installations, covering the following steps:

* **Site Approval** – whereby CNEN approves the site proposed for a particular nuclear facility.

* **Construction Permit (full or partial)** – a permit CNEN authorizes the construction of a nuclear facility after verifying the technical feasibility and the safety concept of the project and its compatibility with the approved site.

* **Authorization for the Use of Nuclear Material** - AUNM – the granting by CNEN of written permission for use of nuclear material in a nuclear facility.

* **Authorization for Initial Operation** - AIO– authorization granted for the initial operating phase of a nuclear facility, upon:
  - verification that construction is substantially completed;
  - evaluation of the Final Safety Analysis Report and of the pre-operational test results;
  - verification of inclusion of all supplemental safety conditions required by CNEN during the construction phase.

* **Authorization for Permanent Operation** - APO– authorization for a nuclear facility to operate on a permanent basis, after completing the phases of initial operation and operation at nominal capacity in normal conditions during a continuous time interval set by CNEN.

3.1.1. **Nuclear licensing - background**

The nuclear licensing of this facility goes back to the nineties when, after submitting the required documentation to CNEN, it obtained site approval in October 1997. At present, the URA has the Authorization for Initial Operation (renewal) granted by CNEN on 4 September 2007.

The construction license was obtained in September 1999 and afterwards the URA plant received the pilot test authorization.

The first Authorization for Initial Operation (AIO) was granted in 2000 and it has been renewed ever since. The last AOI was released in 4 September 2007 and is valid through 24 months.

By means of constant inspections CNEN, monitors URA’s operation whenever necessary for the preparation of additional work to inquire into some technical detail deemed important for clarification.

3.2. Environmental licensing

All project phases are also licensed with the Brazilian Institute for the Environment and Renewable Natural Resources – IBAMA.

Environmental licensing [3] is a rather complex procedure that involves several steps. There is even a constitutional provision for some mandatory procedures to be followed for the licensing of activities that potentially degrade the environment, such as the necessity (Art. 225, Par. 1, V) to prepare a preliminary environmental impact study. Art. 9, IV of Law 6938/81, establishes that “the licensing and review of effectively or potentially polluting activities” are instruments of the National Policy on the Environment.

The main legal document [3] dealing with environmental licensing in the federal sphere is Decree nº 99274 of 6/6/90, where the licensing of activities using environmental resources is governed by articles 17 onwards.

The environmental licensing procedure comprises the granting of the following licenses:

- **Prior License (LP)** – granted in the preliminary phase of activity planning. It contains basic requirements to be met in the siting, installation, and operation phases, in accordance with the municipal, state or federal plans on soil use.

- **Installation License (LI)** – Authorizes the start of site preparation according to the approved detailed design specifications.

- **Operating License (LO)** – A document authorizing, after the necessary verifications, the start of the licensed activity and the operation of pollution control equipment in line with the provisions of the prior and installation license.

In order to clarify the environmental licensing process, CONAMA (National Council for the Environment) Resolution 237/97 (Art. 10) established a minimum road map to be followed in the process, namely:

- Definition by the appropriate state environmental agency, together with the project owner, of the documents, design papers, and environmental studies necessary for starting the licensing process corresponding to the license sought;

- Environmental license application by the project owner, supported by the relevant documents, design papers, and environmental studies; to be publicized on the media;

- Analysis by the appropriate state environmental agency under the National System for the Environment – SISNAMA, of the submitted documents, design papers and environmental studies, and conduct of technical inspections, as necessary;

- Clarification and supplemental information one-time request by the appropriate state environmental agency under SISNAMA, as a result of the analysis of submitted documents, design papers and environmental studies, if any. Such request may be repeated if the clarification and supplemental information are deemed to be inadequate;

- Public hearing, if any, in accordance with the relevant regulation;

- Clarification and supplemental information request by the competent environmental agency as a result of public hearings, if any. Such request may be repeated if the clarification and supplemental information are considered to be inadequate;

- Issuance of conclusive technical opinion and, where appropriate, legal opinion;
- Approval or denial of license application, to be publicized on the media (Resolution CONAMA nº 06/86).

- Additionally, Article 10, Par. 1 establishes that the environmental licensing proceedings shall mandatorily include a City Hall statement certifying that the site and type of project or activity are in accordance with the applicable legislation on soil use and occupation and, where appropriate, with the authorization for vegetation removal and water use issued by the competent bodies.

In short, during a licensing process, the main documents requested are:

- Environmental Impact Study (EIS) and corresponding Environmental Impact Report (EIR) prepared according to a specific Terms of Reference document issued by the environmental agency;
- Detailed design of the facility
- Basic Environmental Plan with the detailing of all required environmental programs.

Such documents are to be submitted in the course of the process. Still, after review thereof, changes and supplemental information may be requested by the environmental agencies.

3.2.1. **Environmental licensing – history**

The environment licensing process for subject facility began in 1996, when INB requested from IBAMA the Prior License for project installation. IBAMA then required the preparation of the Environmental Impact Study (EIS) and the corresponding Environmental Impact Report (EIR).

The EIR must contain a summary of the information included in the EIS in a readily intelligible language in order to provide a clear understanding of the project being licensed.

According to the legislation in force at that time, INB hired an independent firm for preparing the EIS/EIR. On 28 May 1997, IBAMA makes public that it had received the documents and calls a public hearing scheduled for 4 July 1997.

To enable a wide publicizing of such documents, in addition to the copies distributed to the oversight bodies, INB made copies of the EIR available to a number of city halls in the region, namely: Caetité (EIS/EIR), Livramento do Brumado, Ibiassucê, Caculê, Rio do Antônio, Lagoa Real, Igaporã, Guanambi. Copies were also furnished to: the School of Philosophy, Sciences and Letters of Caetité; the District Attorney’s Office of Caetité; the Diocese of Caetité and the City Council of Caetité.

In the period from the delivery of the EIS/EIR to the Public Hearing, INB conducted a series of lectures in the municipalities of Caetité and Lagoa Real for the purpose of disclosing and making available the information contained in the EIR.

Such lectures provided information on:

- nuclear fuel cycle, use of nuclear energy and the existing potential of the uranium province in that region;
- presentation of the process of acquisition of areas of interest to INB for project implementation;
- presentation of the process that would be used to obtain the uranium concentrate;
- presentation of the activities involving licensing, and environmental and occupational control.
In connection with the acquisition of the area needed for project implementation, it should be noted that, due to the existence of several proprietors, INB had to establish a program in order not to cause a great impact on the local society.

In Caetité, INB did not use the instrument of judicial expropriation [4] in the process of acquiring the project land as usually done in implementing large public or private projects. Instead, INB used the “involuntary indemnification” rule. That is, land owners were indemnified in their possessory interest on the land and improvements (crops) ensuing from their working and tilling of the land during the time of their occupation. A value was attributed to the supposed loss of profits, and another to the relocation expenses. The assessment of all such indicators provided the “actual and final value” to be paid the land surface owner for his/her property, by way of compensation. Such value was not only the local market value, but also a historical and cultural value, where nearly all efforts of that rural worker/farmer were assessed and included in the final price of the property.

Therefore, the company’s policy was to negotiate with each inhabitant, assessing his/her property at the actual market value so as to enable all to be able to settle down somewhere else, with no financial loss.

The public hearing held on 4 July 1997 was attended by 974 people representing several segments of the local community. Such event can be considered a landmark for the municipality, inasmuch as it allowed an ample discussion of a project that would contribute to improving the living conditions of the region.

INB then received the Prior License in October 1997 and, after submitting the documents required by the environmental agency, the Installation License on 30 April 1988.

Operating License 274/2002, issued on 29 October 2001, presented conditions on the continuation of social and environmental programs. In addition, the constant concern about possible health problems to the population as a result of the installation of the Uranium Concentrate Plant in the municipality of Caetité, led IBAMA to require that Operating License 274/2002 include a mandatory epidemiological study with the following characteristics:

a) the company to be hired for conducting the study is to work in partnership with the Caetité Secretariat of Health and Regional Health Directorate, which are the competent agencies to enforce the program requirements;

b) the work is to include transversal and longitudinal epidemiological studies for identification of carcinogenic effects on the health of the potentially exposed population, making correlations with the reference municipality, with data from the federal government and the state of Bahia covering the period from 1995 to 2006;

c) the contractor is also to compare the occurrence of neoplasms in the Uranium Concentrate Plant’s area of influence against another region having similar characteristics from a socio-demographic viewpoint but which do not include the presence of natural radiation sources;

d) the second phase of the effort consists in monitoring the original work for a period of five years (up to 2012), the contractor being required to generate corresponding annual reports.

The first phase of this work is nearing completion and expected to be submitted to IBAMA by the end of June 2009.

4. Conclusion

As one can see from the preceding items, the licensing of a nuclear facility is a complex process that develops in the course of years, and where the existence of parallel proceedings (CNEN/ IBAMA) makes it even slower and more expensive to the project owner.
Additionally, one has noticed the tendency to transfer to the project owner the handling of issues that belong to the government. This is a matter that deserves a serious discussion with society at large, because complying with all demands may easily make a project unfeasible.

At present, whereas nuclear licensing maintains a primarily technical approach, environmental licensing has, in turn, sought to incorporate more and more complex demands from the project’s neighboring communities.

Such concern, however, is not new to INB, which has always included safety and control principles into its projects and activities, so as to prevent damage to workers, the environment, and the general public. In fact, as it includes society in decision-making pertaining to activities that may possibly affect society directly or indirectly, the environmental licensing process has been shown to be an opportunity for publicizing the work done by the company, giving it more transparency and, from the viewpoint of the communities, making it more reliable.

Also, it should be noted that licensing is a constant process involving the company, because of the necessity to comply with all requirements of the oversight bodies so as to maintain the licenses obtained and/or to gain license extensions or additions for plants.

For example, INB is now seeking to license a change to the URA mining process, which will shift from open-pit to underground mining. Accordingly, by requirement of CNEN/IBAMA, INB is revising all environmental studies/safety analyses and expanding projects dealing with environmental education and regional insertion.

REFERENCES

Radiation safety and environmental protection issues of uranium mines and mills in Brazil

C.G.S. Costa, L.B. Carvalho, R.R. Carvalho, P.L.S. Dias

Indústrias Nucleares do Brasil - INB, Rio de Janeiro, RJ, Brazil
Indústrias Nucleares do Brasil - INB, Caetité, BA, Brazil

E-mail address of main author: cgscosta@inb.gov.br

Abstract. In 1971 an immense uranium ore deposit was discovered in Caetité, Bahia, at the Northeast region of Brazil, estimated to have about 100 thousands tonnes of uranium concentrate (U$_3$O$_8$). Up to 1995, Brazilian needs were restricted to feed the nuclear reactor Angra 1, then supplied by the first Brazilian mine located in Caldas, Minas Gerais. When the Government decided to finish the next reactor, Angra 2, it became necessary to have larger supplies of uranium concentrate. Therefore, the project of producing uranium in Bahia was elaborated by the Indústrias Nucleares do Brasil - INB, complying with all the strict national and international safety and environmental protection regulations. Considering the mineral characteristics and the very dry weather conditions of the region, it was decided to use the heap leaching process to extract the uranium ore. After been crushed, the ore is piled and irrigated with a sulfuric acid solution. This technique spares the milling, mechanic agitation and filtration phases, allowing, besides a substantial investment reduction and operation at smaller costs. The extraction process accomplishes the uranium concentration by organic solvents, followed by separation by precipitation, and drying. One of the characteristics of the process is that it can be carried out without the need for liberation of effluents to the environment. Recently, the Brazilian Government announced the decision to resume the construction of Angra 3, and there are plans for the construction of four other new nuclear plants. Accordingly, projects for the expansion of the current uranium production capacity in Caetité were developed, and comprise going for underground mining and shifting to conventional leaching. This paper summarizes the present status of radiation safety and environmental protection activities that are in place in and around the uranium mine and milling facilities of Caetité. It describes the workforce radiation protection measures, including dose assessment for direct exposition and incorporation, over the years of operation, and measures envisaged to comply with the future expansion of the enterprise. The environmental protection programme is presented, detailing the continuous monitoring of up to 30-kilometer area around the unit, including the control of: underground and rain water, air, soil, grass, agricultural products and milk. Reference is made to the request made by INB for hosting the IAEA Uranium Production Site Appraisal Team (UPSAT) programme mission, in order to provide assessment of the status of present operational safety and operational practices for both mining and milling at Caetité.

1. Introduction

The Caetité Uranium Concentrate Unit, also known as URA, owned by the Indústrias Nucleares do Brasil – INB [1], is the uranium mine and mill facility in operation at the present moment in Brazil. Located on a mineral rich province with 100 000 tonnes of uranium (U$_3$O$_8$) reserves, it is installed in an area of 1 780 hectares, in the municipality of Caetité, Southeast of Bahia state (13°56’36”S and 42°15’32”W). Project construction began in 1998, exploring the Cachoeira ore deposit (Fig. 1), and involved investments of about US $20 million. Production activities started two years later, based upon the open pit mining of uranium ore, with the average uranium content of 2 900 ppm. The crushed rocks, with particle sizes down to 12 mm or less, are mounted in heap leaching piles of about 25 000 to 35 000 tonnes of mineralized material, irrigated with a sulfuric acid solution. At the processing plant (Fig. 2), the uranium liquor is collected and prepared to have about 2 g/L of uranium, as U$_3$O$_8$. After clarification and filtration of the liquor, the uranium is extracted by means of an organic solvent.
Uranium is then stripped with a NaCl solution, from which it is precipitated as ammonium diuranate (ADU), dried and stocked in drums, ready to be sent abroad for conversion to UF₆.

All the activities of the Caetité Unit are licensed and inspected by the Brazilian Regulatory Authorities: CNEN for nuclear issues and IBAMA for environmental issues, each one with its specific laws and regulations.

**FIG. 1.** Caetité unit – open pit mine, at present.

**FIG. 2.** Milling of uranium – processing plant.
2. Occupational radiation safety

Being a nuclear facility and complying with federal regulations, the Caetité Unit has a Radiation Protection Service (RPS), managed by the Radiation Protection (RP) Officer certified by CNEN. There are several activities and controls developed by the RPS, in order to ensure the proper protection of the health and safety of the workforce, of the people and the environment. Among these, concerning the Occupational Radiation Safety, we may remark:

- **Training of the workforce and other individuals** – all workers and any visitors are subjected to a RP training programme, upon their arrival at the URA. The duration and content of the programme depends on the specific activity to be developed. Workers follow annual retraining programmes.

- **Restricted access to Controlled Areas** – there is the need for an express written authorization, given by the RP Officer, in order to enter any Controlled Area. There are specific procedures to follow upon entrance and exit. Each Controlled Area has a station with full time RP personnel, comprising with the overall inspection, permanence control and dose records, worker protection equipment, as well as area and individual monitoring. The worker protection equipment may include helmets, boots, gloves, protective clothing, mask with filters, more or less stringent depending on the activity pursued.

- **Occupational Monitoring Programme** – there is a comprehensive monitoring programme, approved and inspected by the regulatory body, in order to assess the radiation field levels and the occupational exposure. A summary of the radiation monitoring devices used, or methods, is presented in Table 1, separated as external exposure, internal exposure and surface contamination, either for individual or workplace assessment.

<table>
<thead>
<tr>
<th>Occupational Monitoring</th>
<th>External Exposure</th>
<th>Internal Exposure</th>
<th>Surface Contamination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual Monitoring</td>
<td>TLD</td>
<td>Personal Air Sampler with Alpha/Beta Spectrometry</td>
<td>Geiger Mueller with External Pancake Probe</td>
</tr>
<tr>
<td></td>
<td>Electronic Personal Dosimeter</td>
<td>Internal Dosimetry Excretion Analysis</td>
<td>Personal Hand and Foot Radiation Monitor</td>
</tr>
<tr>
<td>Workplace Monitoring</td>
<td>Dose Rate Meter</td>
<td>High-Flow Air Pump Kit with Alpha/Beta Spectrometry</td>
<td>Surface Scratching with Filter</td>
</tr>
<tr>
<td></td>
<td>Geiger Mueller Counter or Gamma Ray Scintillator</td>
<td>Geiger Mueller with External Pancake Probe</td>
<td></td>
</tr>
</tbody>
</table>

As a result of the Occupational Monitoring Programme, there is full compliance with the dose limit for occupational exposures, established as 20 mSv per year, as required by the Radiation Protection Regulation [2] issued by CNEN (2005). Figure 3 summarizes assessed dose for workers, during the past years. The comparison with production figures illustrates the effectiveness of the continuous optimization procedures, in the last 4 years of operation.
3. Environmental protection programme

The assessment and protection of the health and safety of the members of the public is ensured by means of a rigid Environmental Protection Programme, encompassing the operational (as well as the pre-operational) monitoring of the waste management facilities and the environment.

For the URA Unit, the potential radiation sources are: atmospheric sources—due to open pit detonation, to ore crushing and to heap leaching pile mounting; aquatic sources—due to rainwater run-off or percolation among the solid rock waste deposits, to treated liquid effluent tailing impoundments and to the surface water sedimentation basins; and solid sources—basically due to the solid rock waste deposits. For liquid (surface and underground water) or solid effluents the activity concentration of the following radionuclides is determined: U-238, U-234, Th-230, Ra-226, Pb-210, Th-232 and Ra-228. For air sampling, Rn-222 soil exhalation and atmospheric concentration is also monitored.

The Environmental Monitoring Programme encompass a 30 km radius around the site, and measurements are compared with background levels and pre-operational measurements, taken over a 10 years period before beginning of production. Farm products are taken in the neighborhood, including black beans, corn, manioc, palm (local cactus) and cow milk. Soil and pasture grass at these locations are also collected, together with air sampling.

Table 2 summarizes the monitored matrix, accounting for the number of different sampling points, the monitored parameters and the total average number of results per year, depending on their measurement frequency. Physical-chemical parameters and concentration of stable elements are also determined, for several liquid samples.

Detailed mathematical calculations are used to model the radionuclide transport over the different environmental compartments, starting from each source, in order to achieve reliable assessment of potential contamination and committed doses. Mathematical models and conversion coefficients are based on CNEN regulations, and therefore compatible with ICRP Recommendations and IAEA Safety Standards.

As a result of the Environmental Protection Programme, there is full compliance with the dose limit established as 1 mSv per year, for the relevant critical groups of members of the public, as well as the dose constraint of 0.3 mSv per year, established as the optimization of the Radiological Protection and Safety activities [2].
Table 2. Environmental monitoring programme matrix.

<table>
<thead>
<tr>
<th>Monitoring Type</th>
<th>Number of Monitoring Points</th>
<th>Monitored Parameters⁽¹⁾</th>
<th>Number of Monitoring Results per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radon</td>
<td>26</td>
<td>Radon Concentration in Air</td>
<td>104</td>
</tr>
<tr>
<td>Gamma Radiation</td>
<td>26</td>
<td>Rate of Kerma in Air</td>
<td>104</td>
</tr>
<tr>
<td>Aerosol</td>
<td>7</td>
<td>Radionuclides</td>
<td>140</td>
</tr>
<tr>
<td>Rain Water</td>
<td>7</td>
<td>Radionuclides and pH</td>
<td>126</td>
</tr>
<tr>
<td>Surface Water and Sediments</td>
<td>12</td>
<td>Radionuclides and pH</td>
<td>216</td>
</tr>
<tr>
<td>Underground Water</td>
<td>70</td>
<td>Radionuclides, Physical and Chemical Parameters</td>
<td>8,484</td>
</tr>
<tr>
<td>Soil</td>
<td>14</td>
<td>Radionuclides</td>
<td>70</td>
</tr>
<tr>
<td>Farm Products, Grass</td>
<td>14</td>
<td>Radionuclides</td>
<td>70</td>
</tr>
<tr>
<td>Crushed Ore</td>
<td>2</td>
<td>Radionuclides</td>
<td>60</td>
</tr>
<tr>
<td>Liquid Effluents</td>
<td>21</td>
<td>Radionuclides, Chemical Parameters, pH and Conductivity</td>
<td>1,962</td>
</tr>
<tr>
<td>Total per Year</td>
<td>199</td>
<td></td>
<td>11,336</td>
</tr>
</tbody>
</table>

⁽¹⁾ Monitored Parameters:
Chemical parameters: Mg++, Ca++, Ba++, Mn**, Fe++, Al**, SiO₂, SO₄, F, Na+, K+, Cl, NO₃.

4. Near future plans and conclusion

Projects for the expansion of the current uranium production capacity in Caetité, from annual 400 tonnes to 800 tonnes, are being developed. On the uranium milling, plans are to shift from heap leaching to the more efficient conventional leaching. Pilot tests are being carried out. As for the Cachoeira Mine, plans comprise going for underground mining, scheduled to begin in 2011. Open pit mining is predicted to operate until 2012. Corresponding adaptation of the Occupational Radiation Safety and Environmental Protection Programmes are under way. For the underground mining, ventilation issues and real time radon and daughters monitoring are on top of the concern list, taken by the risk assessment analysis. As for the mid term planning, new ore deposits are under investigation in the Caetité region, envisaging exploration: Engenho Anomaly (about 27 000 tonnes of uranium) and Rabicha Anomaly (about 23 000 tonnes of uranium).

With all this increasing activities running at the URA Caetité Unit, and confident on the Radiological Safety and Environmental Protection Programmes being properly conducted, INB decided to request for hosting an IAEA Uranium Production Site Appraisal Team (UPSAT) programme mission [3], already this year. The purpose is to provide improved assessment of the status of present operational safety and operational practices, for both mining and milling at Caetité, in order to favor a solid ground for the upcoming uranium enterprises of INB, not only in Caetité, but also as a reference for future developments, for example, those planned for Santa Quitéria, in Ceará state.

REFERENCES

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, The IAEA Uranium Production Site
Appraisal Team (UPSAT) programme,
Radiological safety in mining of low grade uranium ores: four decades of monitoring and control in Indian mines

A.H. Khan, V.D. Puranik, H.S. Kushwaha

Health, Safety & Environment Group, Bhabha Atomic Research Centre, Mumbai, India

E-mail address of main author: ahkhan@barc.gov.in

Abstract. The first uranium mine in India commenced operation in 1967 and is now operating up to a depth of about 905 meters. Subsequently, three underground and an opencast mines were opened in the same region. Another underground mine is being developed in the same region and one in southern state of Andhra Pradesh. Workplace monitoring for radiological parameters in each mine commenced right from the beginning of the operations. Monitoring methodologies and ventilation system have undergone several improvements over a period of time. Modifications in ventilation had positive impact of reduction in radon concentrations; consequently the average doses have shown a downward trend. This paper gives an overview of the monitoring for external radiation, radon and the long-lived alpha emitters in the mines. The trend of doses in Jaduguda mines is given for the last four decades and recent data for the other mines are summarised. Efforts made to increase the ventilation and the impacts on radon control are also discussed.

1. Introduction

Many low grade uranium ore deposits have been identified in India. After initial exploratory work, the first uranium mine in India commenced commercial scale operations at Jaduguda in 1967. Subsequently other mines were opened for production in nearby locations [1][2]. Currently four underground and an opencast mines are in operation; two underground mines are in different stages of development. These mines employ large work force. Radiation exposure of mine workers is essentially due to the external gamma radiation from the ore body and internal radiation from inhalation of radon with its short-lived progeny. Exposure to long-lived alpha activity from the airborne ore dust is small. The radiation monitoring and evaluation of dose to workers are regularly carried out in these mines from the beginning of the operations [3][4]. As a matter of policy radiological and environmental safety surveillance is carried out by the Environmental Survey Laboratories of the Bhabha Atomic Research Centre. A brief description of the mines, ventilation system, monitoring methodology and radiation exposure estimates for the workers are given. Impact of ventilation upgradation on radon concentration and dose to workers is also presented. Average annual radiation doses to workers for the last five years in the operating mines are presented. A summary of the average annual exposure of Jaduguda uranium mine workers since the beginning of the operations is also presented in this paper.

2. Mines and the ventilation system

There are four underground and one opencast uranium mines currently operating in the Singhbhum Thrust Belt of eastern India. Another underground mine is being developed at Tumalpalle in the southern state of Andhra Pradesh. The Jaduguda mine was developed in three stages over the years to reach the deepest ore deposit [1]. A central shaft serves as entry for men and material and as main ventilation intake route. A system of exhaust fans located in adits at the top provides adequate air to ventilate the mine workings. The ventilation system is continuously upgraded to provide air quantity commensurate with the operations. The initial ventilation rate of about 78 m³.s⁻¹ in early years was increased to 90 m³.s⁻¹ in 1990s. As deeper levels were developed the ventilation rate was increased
further to 125 m$^3$.s$^{-1}$ in 2002. This was achieved by widening the ventilation routes and increasing the fan capacities.

Initially the series system of ventilation was in vogue where the fresh air entered the lowest levels and travelled to upper levels progressively ventilating the workplaces and finally discharged to open atmosphere through the exhaust fans located in two diagonally opposite adits about 30 metres above ground in isolated locations. This had the disadvantage of contaminating the air during its travel to workplaces in upper horizon. It was later modified to a parallel system of ventilation such that adequate quantity of fresh air enters each haulage level. After ventilating the workplaces the contaminated air joins the return air stream. The fresh air requirement for each haulage level was calculated by taking in to account the emanation rate from the host rock and broken ore stockpiles generally present in the production zones. Taking into account the radon concentration entering a particular haulage level and that in the return air from the most productive zone, the fresh air required for each haulage level of Jaduguda mine was calculated to be 20 m$^3$.s$^{-1}$ [5]. The total quantity for the mine was evaluated depending on the number of haulage levels operating simultaneously and giving due regard to possible leakages.

The Bhatin mine is a relatively small mine developed through adits and winzes to reach the ore body. Entry is through an adit which also serves as intake route for ventilation air and transport of the excavated ore to the surface. An exhaust fan of capacity 50 m$^3$.s$^{-1}$ provides air for ventilation.

Narwapahar mine is one of the most modern mines in the country with a combination of trackless mining through decline and a vertical shaft to reach the deeper ores. Three large fans with a total capacity of 225 m$^3$.s$^{-1}$ provide ventilation to the mine workings [4]. Turamdih mine is also designed for operation with a combination of decline and shaft for production and ventilation purposes. In the initial stages the ventilation rate for this mine is 84 m$^3$.s$^{-1}$. The ventilation in all mines is reviewed periodically and augmented to meet the requirements.

3. Monitoring methodology

3.1. Radon monitoring

A radiation monitoring programme is in operation in all uranium mines and processing plants. The main sources of radiation exposure of workers in low ore grade underground uranium mines are identified as external gamma radiation from the ore body and inhalation of radon ($^{222}$Rn) and its short-lived progeny.

Long-lived alpha activity due to airborne ore dust in mines is evaluated by sampling air through high efficiency filters and counting the alpha activity after allowing sufficient time for complete decay of radon progeny. It is observed in the region of 5 – 10 mBq.m$^{-3}$. Its contribution to the total dose is very small due to the low grade of ore [6][7].

Radon is monitored at all working locations using pre-evacuated scintillation cells. Radon daughter concentrations are also occasionally monitored along with radon to evaluate the equilibrium factor (F). The equilibrium equivalent radon concentrations (Bq.m$^{-3}$EER) for different workplaces are obtained from the measured radon concentration and the equilibrium factor. The radon progeny concentration in units of working level (WL) is obtained by dividing the equilibrium equivalent concentration of radon by 3 700. Although radon concentrations in mines strongly depend on the ventilation rate, factors such as distribution of fresh air, presence of varying quantities of broken ore, radon released by the mine water during its flow through the galleries and auxiliary fans in new development headings make the system rather complex. New development faces are ventilated by auxiliary fans in the initial stages until they are joined with the main ventilation stream. This also has important bearing in the overall average radon concentration in the mine.
3.2. Gamma radiation monitoring

The gamma radiation levels are monitored at all workplaces using radiation survey meters as well as by thermoluminiscient detector based personal dosimeters. Gamma radiation level in workplace depends on the grade of ore present. As a rule of thumb, the ore grade (% U$_3$O$_8$) multiplied by 50 gives the gamma radiation dose rate ($\mu$Gy.h$^{-1}$) [8]. This relationship is useful in estimating the possible exposure levels in a new mining zone.

3.3. Dose evaluation

Using the gamma radiation and radon monitoring data in combination with the average equilibrium factor and occupancy period in different work areas the annual effective dose to the workers is computed as,

$$H_{(mSv)} = \frac{KA\sum_{i}^{n} WLi T_{i}}{170} + \sum_{i}^{n} G_{i} T_{i}$$

where

- $H =$ effective dose, mSv
- $K =$ conversion factor (1 WLM = 5 mSv )
- $WLi =$ radon daughter conc. at ith location (WL)
- $T_{i} =$ time spent at ith location (h)
- $n =$ no. of locations
- $A =$ annual attendance (d/y)
- $G_{i} =$ gamma dose rate at ith location.

The dose evaluation from the area monitoring for radiation and radon with occupancy period is termed as ambient dosimetry. It is supplemented by use of personal dosimetry (PD). The personal dosimeter is an indigenously developed system using thermoluminiscient detectors (TLD) for gamma radiation and solid state nuclear track detectors (SSNTD) for radon measurements. This device comprises of an aluminium chamber of 60 ml volume cylindrical covered with permeable membrane which allows only radon to diffuse in, due to its relatively longer half life, while acting as a barrier for Rn-219, Rn-220 and dust. A 1.8 cm x 3 cm SSNTD film is placed between two TLD chips mounted inside at the other end of the chamber. The TLD and SSNTD in the chamber are replaced every two months. While the TLD chips are processed to give cumulative exposure to gamma radiation and the SSNTD film is etched and electronically counted to give alpha tracks which are correlated to radon exposure. The personal radiation and radon dosimeter is shown in Fig. 1 [9][10].

![FIG.1. Personal radiation and radon dosimeter.](image)
4. Results and discussions

The average gamma radiation level in Jaduguda mine in 2007 was 2.77 µGy.h⁻¹ and radon concentration was 0.24 kBq.m⁻³. In other mines the average external radiation levels were in the range of 1.3 to 2.3 µGy.h⁻¹ and radon concentrations were in the range of 0.32 to 0.57 kBq.m⁻³, respectively. In the Banduhurang opencast mines the average external radiation level and radon concentration were 0.51 µGy.h⁻¹ and 0.03 kBq.m⁻³, respectively.

The radon monitoring data for Jaduguda mine is summarized in Fig. 2. As the ventilation system was augmented in 2002, the results for the radon measurements are given for 5 years before and after the latest ventilation augmentation. There is a reducing trend in radon concentration due to constant modifications in the ventilation. The trend is not uniform because when new mine faces are developed some areas need to be ventilated using auxiliary fans until the gallery is connected to the main ventilation system.

For dose evaluation both the techniques, namely ambient and personal dosimetry, are used. Hence, it is considered appropriate to compare the data obtained by the two systems. A comparison of internal doses due to radon progeny evaluated using the two techniques for different categories of workers is given in Fig. 3. Both techniques are in reasonably good agreement with variations within about 20% [11].

FIG. 2. Trend of radon concentration in Jaduguda mine.

FIG. 3. Comparison of average dose of different categories of mine workers using personal & ambient dosimetry.
The annual average doses to workers in the operating uranium mines during the 5 years from 2003 to 2007 are shown in Fig. 4. The efforts in improving the ventilation to reduce radon concentrations in the mine are reflected in a corresponding downward trend in dose to workers.

While the mines at Jaduguda, Bhatin and Narwapahar have been operating for several decades the Turamdih mine came into operation during the last few years. Banduhurang, also a new mine, is an opencast mine with low grade of ore. There has been overall reduction in the doses to workers of Bhatin and Narwapahar mines also but there are fluctuations. The average doses are currently in the region of 5 to 7 mSv.y\(^{-1}\) for most of the workers. A progressive improvement in ventilation with appropriate distribution of air shows a downward trend. This trend is relatively more prominent in Jaduguda and Turamdih mines. The internal and external dose fractions average around 0.45 and 0.55, respectively, in Jaduguda mine.

The dose record of all mine workers is properly maintained for any future reference and analysis. The annual average doses to Jaduguda mine workers for the last four decades, i.e. from 1965 – 2007 are summarized in Fig. 5.

Radiological monitoring is also carried out during ore processing operations in the mill, tailings management facilities and the environment. The average dose to mill workers during the last 5 years has been around 1.7 mSv.y\(^{-1}\).
Environmental monitoring around the mining facility, especially around the tailings, is carried out regularly by sampling and analysis of effluents and the ground and surface waters to ensure that operation are carried out in compliance with regulatory norms. Analysis of soil, vegetation, plants and local foodstuff is also undertaken periodically. Environmental gamma radiation and radon are also monitored. Impact of mining operations on the environment over the years has been negligible.

New instruments and methodologies are being developed for in-plant and environmental monitoring. Continuous radon monitors have been developed for use as on-line monitors in mines and in the environment.

5. Conclusion

Radiological monitoring and control measures are adopted in all uranium mines in India from the beginning of the operations. As the mines develop and production increases the ventilation system is regularly upgraded to supply adequate fresh air to all operating locations to control radon concentrations at workplaces. The radiation doses to workers have been well within the prescribed constraint of 20 mSv.y^{-1}. The data presented for the recent years show that the average doses in all the mines are in the zone of 5 - 6 mSv.y^{-1}. The improvements in the ventilation system are reflected in a generally downward trend in doses to mine workers. Record of doses received by mine workers is maintained from the beginning of the operations. Radiation and radioactivity levels in ore processing mill and in the environment are also low.

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REFERENCES

dose to uranium mine workers by personal and ambient dosimetry techniques’ Symposium on Radiation Dosimetry and Microanalysis, 2004, DAV College, Amritsar, India.
Temporal changes of radioactive contamination of Ploučnice River
Inundation area, Czech Republic

M. Neznal\textsuperscript{a}, I. Gnojek\textsuperscript{b}, L. Thinová\textsuperscript{c}, L. Neubauer\textsuperscript{d}

\textsuperscript{a}RADON v.o.s., Praha, Czech Republic
\textsuperscript{b}MILIGAL, s.r.o., Brno, Czech Republic
\textsuperscript{c}Czech Technical University, Praha, Czech Republic
\textsuperscript{d}DIAMO s.p., Stráž pod Ralskem, Czech Republic

E-mail address of main author: neznal@clnet.cz

Abstract. The inundation area of Ploučnice river, Czech Republic, has been contaminated by natural radionuclides during the early mining of the uranium ore deposit in the region of Stráž pod Ralskem. A study of temporal changes of contamination was based on a comparison of airborne gamma-ray spectrometric data from 1991 - 1993 and from 2005. After that, detailed ground gamma dose rate measurements were performed at several chosen areas. The results indicate a decrease of contamination with time in a majority of contaminated areas. Advantages and disadvantages of both approaches to the evaluation of the level of contamination (airborne gamma-ray spectrometry, ground gamma dose rate measurements) are described.

1. Introduction

The inundation area of Ploučnice river has been contaminated by natural radionuclides during the early mining of the uranium ore deposit in the region of Stráž pod Ralskem, Northern Bohemia, i.e. in the seventies and in the eighties of the last century \cite{1}. The evaluation of the level of contamination has faced many problems. During several floods that occurred after the primary contamination, the contaminants were spread to a relatively large territory, but the level of contamination became fairly variable. Large regions have not been affected at all, and measured values of gamma dose rate are comparable with the values of natural background. On the other hand, a higher contamination can be found at small areas, often situated far from the river - for example in catchwater drains. Moreover, many contaminated areas are located in places that are difficult to reach. The topographical orientation is also intricate in such places.

A study of temporal changes of contamination was based on a comparison of data obtained using two different methods: airborne gamma-ray spectrometry and detailed ground gamma dose rate measurements.

2. Method

Airborne gamma-ray spectrometric data from 1991 - 1993 and from 2005 (measured using the same instrumentation) were available for the study. In both cases, the airborne survey was realized with the 256-channel gamma-ray spectrometer GR 820 D. Basic parallel flight paths distanced 250 m with the ground clearance of about 100 m were used to cover the whole territory.
As for the results of detailed ground gamma dose rate measurements, several measurement campaigns have been organized during previous 20 years. However only a part of available data is applicable to the analysis of temporal changes of contamination, because different approaches and different measuring techniques were used in the campaigns. To get an information on the present situation in several chosen „hot spots“, a detailed ground survey was performed in 2008. The gamma dose rate on the ground surface and at the height of 1 m above the ground was determined with the field gamma-ray spectrometer Gamma Surveyor and with the radiometer DC-3E-98, respectively.

3. Results and discussion

As output of the airborne gamma-ray spectrometry, different maps of the region of interest have been created: isolines of equivalent uranium concentration in the upper soil layers (ppm eU), isolines of equivalent thorium concentration (ppm eTh), isolines of potassium concentration (% K), and isolines of calculated gamma dose rate at the height of 1 m above the ground (µGy/h). A composite map of equivalent uranium concentrations from 1991 and from 2005 gives information on temporal changes of radioactive contamination. The original scale of the map is 1:50 000, a detail is shown in Fig. 1. The analysis across the map indicates a decrease of radioactive contamination with time in a majority of contaminated areas. Only one exception has been found - the locality on the southern outskirts of the city Mimoň. Over time, the sediments have been gradually eroded, moved and re-deposited on another place. The river probably shows some “self-cleaning ability”.

A decrease of contamination was confirmed by detailed ground gamma dose rate measurements in several chosen „hot spots“. Data from two areas, called „Mimoň - bakery“ and „Mimoň - slaughterhouse“, are summarized in Tables 1 and 2.

Table 1. Radioactive contamination at the area „Mimoň - Bakery“- temporal changes. ground survey 1996 and 2008. Gamma dose rate at the height of 1 m above the ground

<table>
<thead>
<tr>
<th>Parameter / year</th>
<th>1996</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>number of measurements</td>
<td>313</td>
<td>29</td>
</tr>
<tr>
<td>arithmetic mean</td>
<td>0,42 µGy/h</td>
<td>0,24 µGy/h</td>
</tr>
<tr>
<td>minimum</td>
<td>0,10 µGy/h</td>
<td>0,13 µGy/h</td>
</tr>
<tr>
<td>maximum</td>
<td>1,2 µGy/h</td>
<td>0,62 µGy/h</td>
</tr>
<tr>
<td>median</td>
<td>0,34 µGy/h</td>
<td>0,17 µGy/h</td>
</tr>
<tr>
<td>surface area with values higher than 0,2 µGy/h</td>
<td>65 x 40 m</td>
<td>45 x 15 m</td>
</tr>
</tbody>
</table>

Table 2. Radioactive contamination at the area „Mimoň - Slaughterhouse“- temporal changes. ground survey 1996 and 2008. Gamma dose rate at the height of 1 m above the ground

<table>
<thead>
<tr>
<th>Parameter / year</th>
<th>1996</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>number of measurements</td>
<td>311</td>
<td>27</td>
</tr>
<tr>
<td>arithmetic mean</td>
<td>0,29 µGy/h</td>
<td>0,25 µGy/h</td>
</tr>
<tr>
<td>minimum</td>
<td>0,11 µGy/h</td>
<td>0,15 µGy/h</td>
</tr>
<tr>
<td>maximum</td>
<td>0,58 µGy/h</td>
<td>0,46 µGy/h</td>
</tr>
<tr>
<td>median</td>
<td>0,26 µGy/h</td>
<td>0,22 µGy/h</td>
</tr>
</tbody>
</table>

A detailed comparison of airborne gamma-ray spectrometric data and of ground gamma dose rate measurement results illustrates limitations of the maps derived from the airborne survey. One example is presented in Fig. 2.
FIG. 2. Airborne and ground surveys - comparison of the results. Detail. Gamma dose rate derived from airborne measurements, 2005 (µGy/h; underlying map; right scale) vs. gamma dose rate measured at the height of 1 m above the ground, 2008 (µGy/h; coloured circles; left scale).

The airborne survey area resolution is too low to identify small contaminated areas, or significant changes of the level of contamination on a small scale. The level of contamination can be locally much higher than reported on a map derived from the airborne survey. As can be seen in Fig. 2, two points with the gamma dose rate exceeding 1 µGy/h have been found - the points are marked by red circles. The equivalent uranium concentration in the upper soil layers measured by field gamma-ray spectrometer Gamma Surveyor was higher than 200 ppm eU in these points, but the anomaly is so small that it could not be captured by the airborne survey.

4. Conclusions

The analysis of data indicates temporal changes of radioactive contamination of Ploučnice river inundation area. The changes concern the localization of contaminated areas as well as the level of contamination. A decrease of contamination with time has been observed in a majority of contaminated areas.
The airborne survey represents an effective tool for the evaluation of the level of contamination on a large scale. But there are also some limitations of this approach:

- The airborne survey area resolution is limited. Large contaminated areas - such as the uranium mill tailings in Stráž pod Ralskem - can be determined with a good accuracy. However, contaminated areas in the surroundings of Ploučnice river are typically much smaller (~100 m$^2$, or several hundred m$^2$), and the level of contamination is highly variable. Results of the ground gamma dose rate measurements therefore often differ from values derived from the airborne survey. Detailed ground spectrometric measurements also give higher estimates of local uranium concentrations in the upper soil layer.

The airborne survey results are partly influenced by meteorological conditions. At unaffected areas, gamma dose rate values derived from the airborne survey in 2005 are generally higher than those derived from the previous survey in 1991 - 1993. This fact can be explained by lower soil moisture during the airborne survey in 2005.

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REFERENCES

The radiation protection programme at the Nuclear Materials Authority of Egypt

A.G.F. Said

Medical and Radiation Research Department, Nuclear Materials Authority, Cairo, Egypt

E-mail address of main author: abdelghanifs@hotmail.com

Abstract. The development of environmental and safety regulation programme at the Nuclear Materials Authority (NMA) of Egypt is described and the impacts of these developments on various phases of the uranium mining and milling are illustrated. Also, the monitoring and dose assessment for the individual and workplace at the mining operations and laboratories were explained. Meanwhile, a radiation protection programme (RPP) may relate to all phases of a practice or to the lifetime of a facility from design through process control to decommissioning. Therefore, the RPP covers the main elements contributing to protection and safety, and is a key factor for the development of a safety culture. The general objective of RPPs is to reflect the application of management responsibility for protection and safety through the adoption of management structures, policies, procedures and organizational arrangements that are commensurate with the nature and extent of risks. Therefore, the RPP may include protection of workers, the public and the environment. Also, implementation of the optimization principle should be the principal driving force to prevent or reduce potential exposures and to mitigate the consequences of accidents. Therefore, upgrade emergency plan should be ready and active beside written procedures should be used as a part of the work planning process as appropriate. Meanwhile, the education and upgrade training programme introduce in regular intervals, annually, which include an information and recommendation of the international relevant organizations and the basic principles of radiation protection against ionizing radiation. The design and implementation of a monitoring programme should conform to quality assurance and quality control requirements, to ensure that procedures are established and followed correctly, and that records are promptly made and correctly maintained. So, the equipment to be used in the monitoring programme should be suitable for the radiation type(s) and the form(s) of radioactive material encountered in the workplace. Also, the equipment should be calibrated to meet appropriate standards. The Radiation Protection Officer should take part in the planning of activities involving significant exposures, and should advise on the conditions under which work can be undertaken in controlled areas.

Key Words: Radiation Protection Programme, Uranium, Thorium, Radon, Uranium Mine

1. Introduction

The Nuclear Materials Authority (NMA) has been developing a national programme for radioactive mineral exploration, especially uranium, in different sites at Sinai and in the eastern desert of Egypt. So, the Radiation Protection Programme is in to parallel with the most projects and activities of the authority, either in the labs and geological field parities. The principle of optimization of radiation protection is a cornerstone of the international system for radiation protection and is the key driver for ensuring that radiation doses are not just maintained below standards, but are kept to the lowest feasible level throughout the life cycle of a practice involving radioactive materials. This principle is also referred to as the ALARA principle: As Low As Reasonably Achievable, economic and social factors being taken into account. The use of risk management to develop a detailed plan for the identification, control and monitoring of radiation exposure and the management of radioactive wastes is necessary to coordinate the system of radiation protection. The preparation of a formal radiation management is intended to document how best practicable technology has been incorporated into the design and operation of the mine and/or processing plant.
The approved radiation management plan for the mines and Laboratories should contain a radiation monitoring programme that requires, amongst other matters, the monitoring of personal contamination levels and external gamma doses [1]. Due to the use of work category averages in dose assessment, any unusually high or low monitoring result may impact on the exposure estimates for all workers in the particular work category. Safe Work Procedures should be written and reviewed periodically for their effectiveness as well as audited for their actual application in practice. These written work procedures should be referenced in the mine's and labs radiation management plan and must be readily available to, and understood by, all personnel involved.

The site radiation safety officer (RSO) is expected to have a good knowledge of the mean contamination levels and gamma exposures that each work category is normally exposed to. Thus, the RSO should be able to provide professional judgments to make an assessment as to whether any monitoring result appears unusual. Investigation and reporting levels have been identified for radiation parameters area such as Gamma Dose Rate, Personal External Dose, Personal Internal Dose, Airborne Radioactivity, Air-borne Dust, and Radon/Thoron in Air, radionuclides in Water, Stack Emissions and surface contamination. Meanwhile, all employees who may be exposed to radiation should be provided with information on the risks associated with radiation exposure, detailed description of sources and pathways of radiation exposure, and safe working methods.

2. Ionizing radiation

Act No.59 of 1960:

Republican resolution Act No. 59 of 1960, concerning the organization of work with ionizing radiation and the prevention of dangers and the decision executive by Minister of Health No. 630 of 1962 decided the following law.

Concerning the organization of work with ionizing radiation and the prevention of dangers:

1. The ionizing radiation which emitted by radioactive substances or X-ray machines as equipment or accelerators and reactors

2. Using of ionizing radiation does not license unless under the supervision of a person authorized to monitor the implementation of the requirements of radiation protection

3. Constitute a decision of the Minister of Health of the Technical Committee for Ionizing Radiation for licensing in this area.

It should be noted that this act of ionizing radiation does not take into consideration the uranium ore mining and milling, because the substances generated from these activities are qualified as not nuclear substances from the point of view of this act. Therefore, some further decrees based on this act are now under preparation. So in the future this act may also be taken into consideration when planning the rehabilitation activity.

3. Radiation dose limits

3.1. Occupational exposure of workers

The occupational exposure of any worker shall be so controlled that the following limits be not exceeded [2].

(a) an effective dose of 20 mSv per year averaged over five consecutive years

(b) an effective dose of 50 mSv in any single year.

(c) an equivalent dose to the lens of the eye of 150 mSv in a year; and
(d) an equivalent dose to the extremities (hand and feet) or the skin of 500 mSv in a year.

(e) For exposure to radon progeny and thoron progeny, the annual limits on potential alpha energy exposure and inhalation of ore dust corresponding to the limits on effective dose are given as the following: [3]

i. radon progeny: 20 mSv corresponds to 14 mJ•h•m$^{-3}$ which equivalent 4 WLM
ii. thoron progeny: 20 mSv corresponds to 42 mJ•h•m$^{-3}$ which equivalent 12 WLM
iii. uranium ore dust: 20 mSv corresponds to an alpha activity intake of 5700 Bq
iv. thorium ore dust: 20 mSv corresponds to an alpha activity intake of 2500 Bq

3.2. Public exposure

The estimated average dose to the relevant critical groups of members of the public that are attributable to practices shall not exceed the following limits:

a) an effective dose of 1 mSv in a year;

b) in special circumstances, an effective dose of up to 5 mSv a single year provided that the average dose over five consecutive years does not exceed 1 mSv;

c) an equivalent dose to the lens of the eye of 15 mSv in a year; and

d) an equivalent dose to the skin of 50 mSv in a year.

3.3. Total annual dose limits for workers in uranium mines, mills and labs

An annual limit taking into account the combined risks that must be recorded for each worker. The total effective dose ET is calculated according to the following formula:

$$E_T = H_p(d) + \sum_j e(g)_{\text{ing}} I_{\text{ing}} + \sum_j e(g)_{\text{inh}} I_{\text{inh}}$$

where $H_p(d)$ is the personal dose equivalent from exposure to penetrating radiation during the year; $e(g)_{\text{ing}}$ and $e(g)_{\text{inh}}$ are the committed effective dose per unit intake by ingestion and inhalation for radionuclide $j$ by the group of age $g$; and $I_{\text{ing}}$ and $I_{\text{inh}}$ are the intakes via ingestion or inhalation of radionuclide $j$ during the same period and the following relation should be satisfied.

$$\frac{H_p(d)}{DL} + \sum_j I_{\text{ing},L} + \sum_j I_{\text{inh},L} \leq 1$$

where $DL$ is the relevant limit on effective dose, and $I_{\text{ing},L}$ and $I_{\text{inh},L}$ are the annual limits on intake (ALI) via ingestion or via inhalation of radionuclide $j$.

Potential alpha energy exposures to radon progeny and thoron progeny may be determined by integrating the PAEC over the exposure time; they may also be determined from the concentrations of radon and thoron gas in the air by using the following formulas

$$P_{\text{RadP}} = 5.56 \times 10^{-6} \times t \times F_{\text{RadP}} \times C_{\text{Rad}}$$
$$P_{\text{ThP}} = 7.57 \times 10^{-5} \times t \times F_{\text{ThP}} \times C_{\text{Th}}$$

Where; $P_{\text{RadP}}$, $P_{\text{ThP}}$ are the potential alpha energy exposures to radon progeny and thoron progeny, respectively (mJ•h•m$^{-3}$), $t$ is the exposure time (h), $F_{\text{RadP}}$ is the equilibrium factor for radon progeny, $C_{\text{Rad}}$ is the radon gas concentration (Bq/m$^3$), $F_{\text{ThP}}$ is the equilibrium factor for thoron progeny, $C_{\text{Th}}$ is the thoron gas concentration (Bq/m$^3$) [3].
4. Radiation monitoring

Workplace conditions, individual exposures, and assessment of the potential impact an operation may have on the environment must be assessed. It is, therefore, necessary to clearly distinguish between monitoring carried out for the purpose of assessing occupational exposure of workers and monitoring conducted to quantify both the potential for environmental impact of the operation and the possible level of radiation exposure to members of the general public. The main purpose of an occupational radiation monitoring programme is to ensure workforce exposure to radiation remains below the reference level.

4.1. Field measurements

For the detection and measurements of external (gamma-dose) and internal hazards radon and its decay products in the mining environments, both active and passive techniques are applied, for each estimation at different locations in the exploration uranium mines. Active technique needs an external power supply for pumps and electronics devices, but passive technique doesn’t need a power supply as, it uses track etch detectors such as CR-39, LR-115, etc. or thermo-luminescent detectors (TLD) such as CaSO4: Dy or LiF, …etc. Moreover, active technique used in the routine work gives us spontaneous measurements, while passive technique used in the long run and gives us integrating measurements.

4.1.1. Active technique

This technique involves the pumping of a gas through a membrane filter connected with Lucas cell. Radon-222 and Radon-220 (thoron) gases concentration is determined by counting Lucas cell, and the radon/thoron daughters’ products are estimated by counting the filter [4]. There are many techniques for radon and/or radon daughters measurements, for example, the Rolle [5], Kusnetz [6], Markove [7] and Tsivoglou techniques (Tsivoglou et al., 1964). In our study we use Rolle and Kusnetz techniques for one count method and modified Tsivoglou for three count method.

4.1.2. Passive technique

In this technique we use Solid State Nuclear Track Detectors (SSNTDs) such as CR-39 and LR-115 type –II for radon and radon daughter products beside Thermoluminescence Detectors (TLD) for γ – rays. Different authors have investigated the application of SSNTDs for radon dosimeters in mines, in order to build working personnel dosimeter [1][8].

The cup technique is commonly used to study radon emanation from rock materials and radon concentration in mines using track etch plastic detectors. Whereas a plastic cup of about 12 cm height, 7 cm diameter at the open mouth and 5.4 cm diameter at the bottom, is fitted with 1.5 x 1.5 cm² plastic track etch detector attached to the inside and out side the cup. The open mouth of the cup is covered with filter, which permits radon gas to enter the cup and prevents the entrance of radon daughters, therefore, radon gas concentration is determined by counting the inside detector and radon daughter by the outside. A calibrated allyl-diglycol carbonate (C12H18O7) known as CR-39 and cellulose nitrate (C6H8O9N2) which is known as LR-115 type–II were used, which they were placed for 30 days, then the detector is etched at optimum conditions and counted by optical microscope for calculating track density, hence radon and radon daughter products could be determined.

4.1.3. Determination of uranium dust ore concentration (Long-lived alpha emitters)

Concentration of ore dust is measured by collecting air samples on high-efficiency filters paper and analyzing the sample by alpha counting. It is important to ensure that airborne concentrations of uranium be minimized as far below the reference limit and can be determined from the following relation [9].

\[
C_u = \frac{2.2 \times 10^{-7} C}{E vt}
\]
Cu is U Conc. in µCi/cm³, C is alpha count per min., M is the mass of U in µg, t sampling time in min., E is the efficiency of the alpha counter and v is the volumetric sampling rate in L/min.

4.2. General rules for radiation safety in the mines, mills and labs

Each person in the mines mills or labs should observe and obey the rules and instructions that reduce or mitigate radiation hazards as the following:

1. The proposed programme for selecting, using and maintaining personal protective equipment
2. The proposed ventilation and dust control methods and equipment for controlling air quality.
3. Good forced ventilation systems in underground mines to ensure that exposure to radon gas and its radioactive daughter products is as low as possible and does not exceed established safety levels.
4. Limiting the radiation exposure of workers in mine, mill and tailings areas so that it is as low as possible, and in any event does not exceed the allowable dose limits set by the ICRP and IAEA.
5. When performing operations that might produce airborne contamination (i.e., dust evaporations, sanding, or grinding, transfers of unsealed powdered or volatile radioactive material), exhaust ventilation approved by the Radiation Safety Committee shall be used.
6. Smoking, eating or drinking shall not be permitted around radionuclide materials (mine, mill and labs).
7. Food, beverages and their containers shall not be permitted in the laboratory.
8. Pipetting by mouth shall not be permitted in radionuclide laboratories.
9. Microwave ovens in radionuclide laboratories shall not be used for heating food or beverages for personal use.
10. Materials and equipment shall be surveyed before removal from a potentially contaminated area.
11. Protective clothing appropriate for the work conditions shall be worn when working with radioactive materials. This includes laboratory coats, gloves, and safety glasses, appropriate footwear (sandals cannot be worn when working with radioactive materials).
12. All containers of radioactive materials and items, suspected or known to be contaminated, shall be properly labeled (i.e. with tape or tag bearing the radiation).
13. A radiation survey shall be performed by the radionuclide worker at the end of each procedure involving radioactive materials.

4.3. Personal monitoring

1. For individual dose assessment, we are using film badge, and pocket dosimeter in the labs. In the mines worker used the protective equipments beside personal alpha dosimeter and TLD.
2. The individual dose is recorded in the individual file for each worker beside the previous exposure.

3. Some of workers need to health surveillance such as bioassay which includes urine and fecal analysis for determination of uranium and thorium concentration.

4. The medical practitioner should be communicated conclusion in writing to worker and employer.

5. All workers should be informed in an appropriate manner for the results of health examination.

6. All safe worker procedures must be clear and easy to be followed by the users.

7. The personal protective equipment should be used to reduce the radiological risk beside the dose record and health surveillance (we apply the recommendation of the safety standard issued by IAEA and ICRP in radiation control).

8. In particular, personal radiation exposure data for all designated employees should be available at any time and regularly updated. This should be facilitated by the use of a computer database.

5. The radioactive waste management

Although the milling process recovers about 95 percent of the uranium present in ores, the residues, or tailings, contain several naturally-occurring radioactive elements, including uranium, thorium, radium, polonium, and radon, beside the solid and liquid wastes that are generated in the mining and milling of ores and which should be managed throughout the lifetime of the mining and milling facilities that include sludges, contaminated materials, waste rock, process water, leaching fluids, seepage and runoff.

The tailings are categorized as radioactive waste, disposal may be undertaken by returning to the mine pit, preferably dispersed in the initial mine tailings, or stored with appropriate safeguards if future economic use is foreseen [10].

In the laboratories the radioactive waste should be classified and disposed in the storage. The storage area with radiation level exceeding the permissible limit should be isolated and classified as restricted area and it should be far enough from the office and workers restricted area.

6. Transport of hazardous materials

Package and transport all hazardous materials (radioactive and non-radioactive) – including products, residues, wastes, and contaminated materials – safely, securely, and in compliance with laws and regulations. With radioactive materials, adhere to IAEA Regulations for the Safe Transport of Radioactive Material, relevant IAEA Safety Guides, applicable international conventions, and local legislation. Also, security and safety of Sealed Radioactive Sources and Nuclear Substances should be following up due physical, chemical and radiological properties during transportation, storage and uses. Routine monitoring made at the surface of and at a certain distance from the packages and conveyances should be detailed in the RPP to ensure both that the current authorized limits for radiation levels and surface contamination are met and that the scope of the RPP has been well defined. The equipment to be used should be suitable for the types of radiation encountered and should be calibrated to meet the appropriate performance standards.

7. Decommissioning and site closure

In designing any installation, plan for future site decommissioning, remediation, closure and land use as an integral and necessary part of original project development. In such design and in facility operations, seek to maximize the use of remedial actions concurrent with production. Ensure that the
long-term plan includes socio-economic considerations, including the welfare of workers and host communities, and clear provisions for the accumulation of resources adequate to implement the plan. Periodically review and update the plan in light of new circumstances and in consultation with affected stakeholders. In connection with the cessation of operations, establish a decommissioning organization to implement the plan and safely restore the site for re-use to the fullest extent practicable. Engage in no activities – or acts of omission – that could result in the abandonment of a site without plans and resources for full and effective decommissioning or that would pose a burden or threat to future generations.

8. The emergency plan against nuclear accidents.

The emergency response programme has three primary objectives. The first objective is to take action at the source of the accident to mitigate or reduce the potential risk. The second objective is to ensure that people will not receive doses high enough to result in deterministic health effects induced by the accident. The third objective is to take reasonable actions to reduce the chance of stochastic health effects. It’s obvious that the second and the third objectives are directly related to human health. Therefore, every person participating in emergency response has to know and understand the steps and topics of emergency; and the relationships between radiation physics, radiation induced health effects and radiation protection. Therefore, a periodic training and exercises should be performed in order that the plan should be ready and active.

9. The training programme

All employees who may be exposed to radiation and all persons responsible for the implementation of the RPP beside the radiation protection officers and radiation protection experts should receive appropriate training. Senior management and employees in other departments (such as public relations, human resources, etc) should also be provided with information on risks associated with radiation exposure.

9.1. Employees training

Employees whose work may impact on the levels of radiation exposure should be provided with basic information. Therefore, the training program should include:

1. Basic of radiation and radioactivity (detection, units and measurements)
2. The principles of radiation protection and ALARA concepts.
3. The radiation protection in uranium mines, mills and tailing beside laboratories.
4. Effect of radiation on the biological system
5. Exposure limits
6. Safety Responsibilities
7. Emergency Procedures
8. Regulatory References

9.2. Radiation protection officer training

Beside the employees training topics, training for radiation protection officers will vary considerably depending on the radiation application, but all training should contain a certain amount of common core information on protection and safety. The depth to which each topic is covered should depend on the specific practice in which the person is being trained, and should also take into account the magnitude of the potential hazards associated with the application. Radiation protection officers need to have specific personal attributes, such as communication skills, leadership and analytical skills, human–machine interface skills and multitask management skills, which can be stimulated during training through practical exercises.
9.3. **Qualified experts training**

Training for qualified experts should provide the broad knowledge of protection and safety. This level of knowledge may be obtained by formal education, specific training and work experience. Additionally, qualified experts need to have a thorough knowledge of specific topics related to their field of expertise and also need to keep abreast of developments in their field. Qualified experts need to have highly developed personal attributes, including communication, analytical and leadership skills, since they provide training and give advice to a wide range of personnel, such as workers, managers, health professionals or staff of government authorities.

10. **Quality assurance and quality control**

Monitoring and surveillance programmes should be subject to adequate arrangements as regards quality assurance that provides for a disciplined approach to all activities affecting quality, where appropriate, verification that each task has met the objectives and that any corrective action has been implemented. An adequate quality assurance programme for the monitoring and surveillance has to satisfy the basic general requirements established by the regulatory authority for quality assurance in the fields of environmental protection and radiological protection. Therefore, an appropriate quality assurance programme includes:

1. Design and implementation of the monitoring and surveillance programmes which include determination of suitable equipment and procedures, and their documentation.

2. Proper maintenance, testing and calibration of equipment and instruments to ensure that they function properly;

3. Calibration standards that is traceable to national and international standards;

4. Quality control mechanisms and procedures for reviewing and assessing the overall effectiveness of the monitoring and surveillance programme;

5. Uncertainty analysis;

6. Record keeping requirements.

11. **General conclusion**

The goal of a radiation protection programme is to keep radiation exposures to workers and the general public to levels as low as reasonably achievable (ALARA). Therefore, the key elements necessary to develop an effective Radiation Protection Programme (RPP) should be established. The development and conduct of an effective monitoring and surveillance plan needs continual interaction between the regulatory authority, the affected community and the mine or mill operators. Radiation protection is only one element in ensuring the overall health and safety of workers in operations in the mining and processing of raw materials beside the laboratories safety control. The radiation protection programme (RPP) may relate to all phases of a practice or to the lifetime of a facility from design through process control to decommissioning. The implementation of the optimization principle should be the principal driving force to prevent or reduce potential exposures and to mitigate the consequences of accidents. Therefore, upgrade emergency plan should be ready and active beside written procedures should be used as a part of the work planning process as appropriate. Meanwhile, the education and upgrade training programme introduce in regular intervals, annually, which include an information and recommendation of the international relevant organizations and the basic principles of radiation protection against ionizing radiation. The design and implementation of a monitoring programme should conform to quality assurance and quality control requirements, to ensure that procedures are established and followed correctly, and that records are promptly made and correctly maintained.
REFERENCES

Overview of the IAEA national technical cooperation projects on uranium exploration in Argentina

L. López, R. Ferreyra
National Atomic Energy Commission (CNEA), City, Argentina
E-mail address of main author: lopez@cnea.gov.ar

Abstract. Since 1993, three IAEA National Technical Cooperation Projects have been developed in Argentina. Their objectives have been to improve the capability of the country to strategically plan and efficiently carry out its uranium exploration program.

1. Introduction

The uranium mining cycle activities in Argentina began in the 1950s. Then, the systematic exploration led to the discovery of several uranium deposits and, consequently, seven mining centers were in operation in the country and produced a historical total of 2,500 tonnes of U.

In 1992, for economic reasons Argentina began to import uranium, a situation that progressively led to the closing of national production in 1998. In spite of that, the CNEA has continued to be active in several uranium projects that have progressed to different degrees of development.

Furthermore, since 1993 three National Technical Cooperation Projects have been developed through the IAEA’s technological transfer devoted to uranium favorability and exploration, gamma-ray spectrometry surveys and ISL, respectively.


In the context of this TC project, new skills were developed to carry out the assessment of the uranium favorability of the country. This program consists of the regional assessment of the country’s overall uranium potential, following the method applied by the National Uranium Resource Evaluation (NURE) from the United States. For these studies the national territory is divided into 57 research units where the speculative resources, taking into account the presence of existing uranium deposits in the area or in a similar geological environment, are determined. At present, this program is 55% completed [1][2][3][4].

This project has contributed to providing new guidelines for the exploration of volcanic and caldera related, sandstone and granitic geological types of uranium deposits. Main cooperation activities were developed in the San Rafael (Lower Permian) and San Jorge Basins (Cretaceous) and the Pampean Ranges (Lower Paleozoic). These areas represent some of the more important regions for uranium exploration in the country [5].

In addition, 140,000 km² of airborne gamma ray spectrometry data from Patagonia and Pampean Ranges [6][7], were reprocessed and back-calibrated [8]. These surveys were originally conducted for detecting potential uranium mineralisation, an objective that was clearly reached, but the production of
a new digital archive enhanced the application of this information in the fields of geological mapping and environmental issues [9][10].


In the framework of this TC project, new capacities for the detection, processing and interpretation of airborne, carborne and ground gamma ray spectrometry data were developed.

A carborne gamma–ray spectrometer system was successfully installed and calibrated, so that the gamma-ray count rates could be converted to ground concentrations of potassium, uranium and thorium [11]. This carborne system has a 4.2 l NaI detector mounted on the roof of a truck and can record up to 512 channels of gamma-ray spectral data [12].

This new gamma-ray spectrometer system increased the national capability for uranium exploration. Moreover, it enhances CNEA’s ability to conduct ground-based surveys to support mineral exploration and environmental studies [13].

4. Technical Cooperation Project ARG 3/012-14 "Geology favorability, production feasibility and environmental impact assessment of uranium deposits exploitable by the in situ leaching (ISL) technology" (2007 - up to date)

This is an ongoing project that is linked to the IAEA Regional Technical Cooperation Project named “Upgrading of Uranium Exploration, Exploitation and Yellowcake Production Techniques taking Environmental Problems into Account (RLA 3006)” and considers the study of different areas of interest within the uranium mining cycle of ISL [14][15].

At the favorability stage, some Tertiary sandstone units of the Neuquina Basin are being investigated through the compilation of previous information, field reconnaissance, the gathering of logging and sampling data from oil wells, petrophysical determinations and petrological studies [16].

Also, in the Cretaceous San Jorge Basin based on airborne gamma ray spectrometry surveys, field geological reconnaissance and underground information, some targets with ISL possibilities were defined. In some locations, inferred and prognosticated uranium resources have been defined and a drilling program has been set up to be carried out this year [17].

Finally, the TC project includes pilot tests in order to determine the production feasibility of the remaining resources, evaluated in 216 t U, by block leaching mining in the Don Otto deposit [1]. This deposit was exploited from 1963 to 1980 by underground mining, obtaining a total of 275 tonnes of U [18].

According to the present knowledge, ISL should be considered as a sustainable alternative for uranium production in the future of our country.

5. Final considerations

The advancements in the nuclear field reached by Argentina have been historically supported by the existence of uranium mineral resources in the country. The existence of favorable environments and advanced exploration programs, configure promising conditions to develop new uranium resources that would allow Argentina to increase the participation of the nuclear technology in the energy generation of the country. In this general framework, the role of the IAEA Technical Cooperation Projects is highly relevant for improving the capability of Argentina to strategically plan and efficiently carry out a variety of uranium projects.
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REFERENCES

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  Transport of Radioactive Material 20
  Radiation Protection 21
  Radioactive Waste Management 22
  Safety Analysis 24
  Legal and Governmental Aspects 24

NUCLEAR POWER 25
  Nuclear Power Planning and Economics 26
  Nuclear Power Operations 27
  Reactor Technology 27
  Quality Assurance 30
  Qualification and Training of Personnel 30
Radiotherapy

Development of Procedures for in Vivo Dosimetry in Radiotherapy
IAEA Human Health Reports No. 8
This publication, which draws on the experiences of an IAEA coordinated research project (CRP) and on input from experts in the field, provides a comprehensive overview of the development of procedures for in vivo dosimetry in radiotherapy. It elaborates on the technology behind in vivo dosimetry and describes an initial set of in vivo measurements. Emphasis is given to patient dose studies, both evaluating the clinical value of in vivo dosimetry and comparing different in vivo dosimetry systems in a clinical setting. The findings of the CRP, which are summarized in this publication, will serve as a useful resource for hospital physicists seeking to establish an in vivo dosimetry programme in a radiotherapy centre and will help them in the selection of appropriate in vivo dosimetry systems.

(Forthcoming 2013) • ISBN 978-92-0-141610-0 • STI/PUB/1606 • €34.00

IAEA Human Health Reports No. 6
Clinical guidelines for the management of cervical cancer exist in the published literature. However, these guidelines have usually been developed in and for an affluent environment where all modern diagnosis and treatment modalities and tools are available to the practitioner. This publication is aimed at radiation oncologists working in centres with limited resources and treating a large number of patients with cervical cancer. The approach and techniques recommended are intended to be evidence based, simple, feasible and resource-sparing, to the extent that this is possible when dealing with a complex treatment modality such as radiotherapy.

(Forthcoming 2013) • ISBN 978-92-0-128810-3 • STI/PUB/1556 • €18.00

Practical Guidance on Peptide Receptor Radionuclide Therapy (PRRNT) in Neuroendocrine Tumours
IAEA Human Health Series No. 20
This publication provides comprehensive multidisciplinary guidance to promote standardized, effective and safe implementation of best practices for treating neuroendocrine and gastro-entero-pancreatic tumours through applying peptide receptor radionuclide therapy (PRRNT). Taking into account the latest international classifications of neuroendocrine tumours, both PRRNT as a sole treatment and as a treatment in combination with other options are considered. Comprehensive protocols for employing either $^{90}$Y or $^{177}$Lu tagged somatostatin receptor-targeting peptides and clinically tested protocols for renal protection are presented. The publication comprises a comprehensive compilation of medical evidence and experience. Furthermore, it contains clinical presentations, eligibility criteria and means of assessing the effectiveness of therapy utilizing molecular and morphological medical imaging techniques. The publication is a practical reference for specialists in clinical oncology and in nuclear medicine deploying and executing a comprehensive programme for treating patients with neuroendocrine tumours.

(123 pp., 5 figs; 2013) • ISBN 978-92-0-129210-0 • STI/PUB/1560 • €39.00

Radiotherapy in Palliative Cancer Care: Development and Implementation
IAEA Human Health Reports No. 2
Palliative care is increasingly recognized as an important component of quality care for cancer patients. Improving access to, and availability and quality of, comprehensive palliative care in cancer treatment is an important and ongoing global challenge. This publication focuses on radiotherapy as a major tool and gives summaries of current approaches in palliative radiotherapy and care. It describes the steps needed to enhance access to and quality of care, and to incorporate palliative radiotherapy and palliative care within an integrated multidisciplinary approach. It is hoped that this publication will be a resource for administrators, specialists and teachers working to improve the management of palliative care and radiotherapy for patients.

(53 pp., 2 figs; 2012) • ISBN 978-92-0-109009-6 • STI/PUB/1388 • €16.00

Record and Verify Systems for Radiation Treatment of Cancer: Acceptance Testing, Commissioning and Quality Control
IAEA Human Health Reports No. 7
This publication serves as a useful guide for medical physicists in radiation oncology, radiation oncologists and radiation therapists, ensuring accuracy, safety and quality in radiation therapy. Record and verify systems (RVSs) were developed to reduce the risk of treatment errors in radiation oncology. These have recently evolved into complete radiotherapy information management systems that interface with imaging systems, treatment planning computers, and treatment delivery systems. To function as intended, RVSs must be subject to a comprehensive
quality assurance (QA) programme. This publication provides practical guidelines for a comprehensive QA programme and its implementation. It describes the QA programme, including acceptance tests and the commissioning process that should be used in conjunction with the installation of a new RVS. It is also highlighted that some of the tests performed at installation must be repeated regularly as part of the periodic quality control checks.

(Forthcoming 2013) • ISBN 978-92-0-141710-7 • STI/PUB/1607 • €22.00

MEDICAL PHYSICS, DOSIMETRY AND DIAGNOSIS

Diagnostic Radiology Physics: A Handbook for Teachers and Students

This publication is aimed at students and teachers involved in programmes that train medical physicists for work in diagnostic radiology. It provides a comprehensive overview of the basic medical physics knowledge required for the practice of modern diagnostic radiology in the form of a syllabus. This makes it particularly useful for graduate students and residents in medical physics programmes. The material presented in the publication has been endorsed by the major international organizations and is the foundation for academic and clinical courses in both diagnostic radiology physics and in emerging areas such as imaging in radiotherapy.

(Forthcoming 2013) • ISBN 978-92-0-131010-1 • STI/PUB/1564 • €90.00

Dosimetry in Diagnostic Radiology for Paediatric Patients

IAEA Human Health Series No. 24

This publication draws on an IAEA coordinated research project and provides recommendations specific to measurement and interpretation of radiation dose to children as a result of undergoing diagnostic radiological examinations. It complements the work of Dosimetry in Diagnostic Radiology: A Code of Practice (Technical Report Series No. 457) and extends this work in methodologies for dosimetry in clinical environments to that required for non-adult patients. It includes dosimetry methodologies for general radiography, fluoroscopy and computer tomography for both phantom and patient measurements. Details are given on dose audit strategies that take into account the size of children and on how the results of such audits can be used to indicate or be related to diagnostic reference levels. The effects of radiation on non-adults are also reviewed, as are the factors involved in the management of paediatric dosage in the clinical setting.

(Forthcoming 2013) • ISBN 978-92-0-141910-1 • STI/PUB/1609 • €46.00

Justification of Medical Exposure in Diagnostic Imaging
Proceedings of an International Workshop held in Brussels, Belgium, 2–4 September 2009
Proceedings Series

This is the proceedings of an international workshop on justification of medical exposure in diagnostic imaging, jointly organized by the IAEA and the European Commission. The workshop brought together experts from many countries and organizations to discuss how to ensure more effective application of justification in diagnostic imaging. Major areas that need action were identified, such as the coordination of methods and evidence used as a basis for clinical imaging recommendations, engagement of all relevant organizations in the deployment of these recommendations, and involvement of manufacturers and referring healthcare providers. Furthermore, the important role of education and training was re-emphasized. In the conclusion, the workshop participants highlighted that regulatory authorities have a key role in ensuring effective justification, and that an effective partnership with the medical community must be maintained to do this.

(175 pp., 24 figs; 2012) • ISBN 978-92-0-121110-1 • STI/PUB/1532 • €40.00

Nuclear Cardiology: Guidance and Recommendations for Implementation in Developing Countries

IAEA Human Health Series No. 23

This publication, which accompanies Nuclear Cardiology: Its Role in Cost Effective Care (IAEA Human Health Series No. 18), discusses non-invasive imaging modalities with an emphasis on myocardial perfusion imaging (MPI). MPI is one of the most complex nuclear techniques and by far the most widely used for non-invasive detection of coronary artery disease. The book covers all aspects of this modality, from clinical indications to reporting. Chapters describe clinical scenarios and provide examples of good strategies and recommendations of good practice. The aim of the publication is to help strengthen current nuclear cardiology practices, so that they meet accepted standards and that providers can deliver better quality services to the population. Target readers are nuclear medicine physicians, cardiologists and cardiac surgeons, but also all other clinical specialists involved in managing and treating cardiac diseases and particularly coronary artery diseases.

(108 pp., 27 figs; 2012) • ISBN 978-92-0-131710-0 • STI/PUB/1566 • €32.00

Nuclear Cardiology: Its Role in Cost Effective Care

IAEA Human Health Series No. 18

This publication presents a comprehensive overview of cardiovascular disease (CVD) as a public health problem in developing countries, the relative role of nuclear
cardiology methods within a scenario of unprecedented technological advances and the evidence behind recommendations. The potential role of non-invasive functional imaging in the diagnosis of obstructive coronary artery disease and more widely in defining the global burden of CVD is also discussed, as well as the need for training, education and quality assurance in nuclear cardiology practice.

(87 pp., 32 figs; 2012) • ISBN 978-92-0-174710-9 • STI/PUB/1516 • €30.00

Quality Assurance Programme for Computed Tomography: Diagnostic and Therapy Applications

IAEA Human Health Series No. 19

This publication presents a harmonized approach to quality assurance in the field of computed tomography applied to both diagnostics and therapy. It provides a careful analysis of the principles and specific instructions that can be used for a quality assurance programme for optimal performance and reduced patient dose in diagnostic radiology. In some cases, radiotherapy programmes are making a transition from 2-D to 3-D radiotherapy, a complex process which critically depends on accurate treatment planning. In this respect, the authors also provide detailed information about the elements needed for quality assurance testing, including those relating to accurate patient characterization as needed for radiotherapy treatment planning.

(171 pp., 43 figs; 2012) • ISBN 978-92-0-128910-0 • STI/PUB/1557 • €48.00

Quantitative Nuclear Medicine Imaging: Concepts, Requirements and Methods

IAEA Human Health Reports No. 9

This publication reviews the current state of the art of image quantification and provides a solid background of tools and methods to medical physicists and other related professionals who are faced with quantification of radionuclide distribution in clinical practice. It describes and analyses the physical effects that degrade image quality and affect the accuracy of quantification, and describes methods to compensate for them in planar, single-photon emission computed tomography (SPECT) and positron emission tomography (PET) images.

(Forthcoming 2013) • ISBN 978-92-0-141510-3 • STI/PUB/1605 • €33.00

Radiation Protection in Paediatric Radiology

Safety Reports Series No. 71

This publication provides guidance to radiologists, other clinicians and radiographers/technologists involved in diagnostic procedures using ionizing radiation with children and adolescents, and should also be of value to medical physicists and regulators. It focuses on the measures necessary to provide protection from the effects of radiation using the principles established in the IAEA’s International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources, and the priority accorded to the area. The emphasis throughout is on the special requirements of paediatrics.

(111 pp., 2 figs; 2013) • ISBN 978-92-0-125710-9 • STI/PUB/1543 • €38.00

Roles and Responsibilities, and Education and Training Requirements for Clinically Qualified Medical Physicists

IAEA Human Health Series No. 25

There is a shortfall of well trained and clinically qualified medical physicists working in radiation medicine. The roles, responsibilities and clinical training requirements of medical physicists have not always been well defined or well understood by health care professionals, health authorities and regulatory agencies. To fill this gap, this publication provides recommendations for the academic education and clinical training of clinically qualified medical physicists, including recommendations for their accreditation certification and registration, along with continuous professional development. The goal is to establish criteria that support the harmonization of education and clinical training worldwide, as well as promote the recognition of medical physics as a profession.

(Forthcoming 2013) • ISBN 978-92-0-142010-7 • STI/PUB/1610 • €32.00

Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS)

Proceedings of an International Symposium held in Vienna, Austria, 9–12 November 2010 (2 Volumes)

Proceedings Series

This publication presents the proceedings of an international symposium on standards, applications and quality assurance in medical radiation dosimetry. It includes a selection of peer reviewed papers that were presented at the symposium. The symposium provided a forum for physicists and scientists of medical institutions, research centres and standards laboratories to discuss advances in radiation dosimetry made during the past decade and to exchange scientific knowledge. The topical sessions included all specialties in radiation medicine (radiation oncology, nuclear medicine and diagnostic radiology) and radiation protection dosimetry, with a specific focus on those areas where the standardization of dosimetry has improved in recent years (brachytherapy, diagnostic radiology and nuclear medicine). One session was exclusively devoted to the challenging issues of dosimetry in small and non-standard radiotherapy beams. The publication summarizes the present status and outlines future trends in medical radiation dosimetry, and also identifies possible areas for improvement.

(925 pp.; 2012) • ISBN 978-92-0-116210-6 • STI/PUB/1514 • €120.00
Assessment of Iron Bioavailability in Humans Using Stable Iron Isotope Techniques
IAEA Human Health Series No. 21

This publication on the assessment of iron bioavailability was developed as part of the IAEA’s continuing efforts to transfer knowledge and technology on the use of stable isotope techniques in nutrition. It provides information on the theoretical background and practical application of state of the art methodology to measure human iron absorption and dietary iron bioavailability using stable (non-radioactive) isotopes. These techniques can be used to guide fortification and food based strategies to combat iron deficiency, which remains unacceptably high among infants, children and women of childbearing age in developing countries.

(78 pp., 14 figs; 2012) • ISBN 978-92-0-126510-4 • STI/PUB/1544 • €26.00

Body Composition Assessment from Birth to Two Years of Age
IAEA Human Health Series No. 22

This publication was developed by an international group of experts as an integral part of the IAEA’s efforts to contribute to the transfer of technology and capacity building in this field in order to assist Member States in their efforts to improve the nutrition and health of the most vulnerable population groups, infants and young children. The book provides practical information on the assessment of body composition from birth up to two years of age and is intended for nutritionists, paediatricians and other health professionals. The body composition assessment techniques included in this publication were selected as methodologies with the highest potential for standardization globally — based on considerations such as access to equipment, cost and the training needs of staff — and include stable isotope dilution for total body water assessment, as well as dual energy X ray absorptiometry and air displacement plethysmography. In addition, the importance of standardization of anthropometric measurements is highlighted in this book, as basic measurements of body weight and length are crucial for accurate body composition assessment.

(Forthcoming 2013) • ISBN 978-92-0-127710-7 • STI/PUB/1550 • €36.00

Cyclotron Produced Radionuclides: Guidance on Facility Design and Production of \(^{18}\text{F}\)Fluorodeoxyglucose (FDG)
IAEA Radioisotopes and Radiopharmaceuticals Series No. 3

This publication provides practical information for planning and operating a fluorodeoxyglucose (FDG) production facility, including design and implementation of the laboratories, facility layout, equipment, personnel and quality assessment of FDG. Also included is information useful for assessing the resource requirements, planning and aspects necessary for compliance with the applicable national regulatory requirements for manufacturing of radiopharmaceuticals.

(153 pp., 11 figs; 2012) • ISBN 978-92-0-117310-2 • STI/PUB/1515 • €55.00

Cyclotron Produced Radionuclides: Operation and Maintenance of Gas and Liquid Targets
IAEA Radioisotopes and Radiopharmaceuticals Series No. 4

This publication, which draws on the results of an IAEA coordinated research project and on input from dedicated experts in the field, provides a comprehensive overview of the technologies involved in the manufacture and operation of liquid and gas targets for cyclotron based production of radioisotopes. It covers the technology behind targetry, techniques for preparation of targets, irradiation of targets under high beam currents, target processing, target recovery, etc. The publication will be useful to scientists and technologists interested in translating cyclotron based radioisotope production into practice, as well as to postgraduate students in the field.

(104 pp.; 2012) • ISBN 978-92-0-130710-1 • STI/PUB/1563 • €35.00
Non-HEU Production Technologies for Molybdenum-99 and Technetium-99m

IAEA Nuclear Energy Series No. NF-T-5.4

Technetium-99m (99mTc) is used in approximately 85% of diagnostic imaging procedures in nuclear medicine worldwide. Interruptions in the supply of molybdenum (99Mo), which is used to produce 99mTc, prompted governments and international agencies to step up efforts to identify both short- and long-term solutions to supply shortages. These calls for action resulted in economic and technology studies on the 99Mo supply chain. The present publication supports global efforts to eliminate the civilian use of highly enriched uranium in 99Mo/99mTc production and proposes several alternative or supplementary technologies.

(60 pp., 20 figs; 2013) • ISBN 978-92-0-137710-4 • STI/PUB/1589 • €24.00

Nuclear Data for the Production of Therapeutic Radionuclides
Technical Reports Series No. 473

This publication reports the results of an IAEA coordinated research project on nuclear data for the production of therapeutic radionuclides. The aim was to provide standardized data for the production of radionuclides for therapeutic purposes, embracing current and possible future needs. Experimental data compilations, theoretical calculations and evaluations were carried out for each of the reactions. The recommendations for production of both established and emerging radionuclides are discussed, and the analysis carried out to produce the recommended data is also presented. The improved quality of the nuclear data will make reactor and accelerator production of therapeutic radionuclides much more efficient, and should also enhance their quality through improved purity of the product. The current publication comprises newly evaluated data for both reactor and accelerator production of therapeutic radionuclides, based on more than fifty different production reactions.

(382 pp., 88 figs; 2012) • ISBN 978-92-0-115010-3 • STI/DOC/010/473 • €75.00
Quality Control for Expanded Tsetse Production, Sterilization and Field Application
IAEA TECDOC Series No. 1683
The use of the sterile insect technique for the control or eradication of tsetse flies is progressing towards the first large scale programmes on mainland Africa. To enable these programmes, the rearing of tsetse flies has to be much expanded, and with the expansion, issues of quality control become more important. This publication provides an analysis of several aspects of quality in tsetse fly production and expands or enhances many of the current quality control procedures.

Greater Agronomic Water Use Efficiency in Wheat and Rice Using Carbon Isotope Discrimination
IAEA TECDOC Series No. 1671
Water scarcity, drought and salinity are among the most important environmental constraints challenging crop productivity in the arid and semi-arid regions of the world, especially rainfed production systems. This publication presents the outcome of an IAEA coordinated research project aimed at increasing agronomic water use efficiency in wheat and rice production. The studies show that the carbon isotope discrimination (CID), which is the ratio of the variation of carbon-13 to carbon-12 in plant samples (leaf and grain), is a good selection tool for identifying high yielding genotypes of wheat under drought stress environments for both pre-anthesis and post-anthesis stages. The CID of flag leaf can also potentially be used to select rice genotypes for salinity tolerance and parental lines for breeding. The experience gained through these studies will be highly relevant to the needs of developing Member States in Africa, Asia and Latin America.
Instrumentation for Digital Nuclear Spectroscopy
IAEA TECDOC Series No. 1706
This publication presents the results of an IAEA technical meeting on instrumentation for digital spectroscopy. The meeting provided a forum for discussion of ongoing issues regarding implementation of digital signal processing (DSP) in nuclear spectroscopy. Representatives from industry, research institutes and utilities presented recent experiences with DSP. New opportunities in high resolution spectrometry and the advantages of their application in hand-held field instruments and in remote and unattended nuclear spectrometry systems were also discussed and reviewed.

Measurement and Calculation of Radon Releases from NORM Residues
Technical Reports Series No. 474
This publication provides a comprehensive overview of the prediction, measurement and monitoring of radon releases from NORM residues, including uranium mining and milling residues. It presents factors controlling radon emanation and exhalation from residue materials, repository cover characteristics, methods for predicting radon exhalation flux (including models and the required input parameters and variables), measurement methods for radon concentration in soil gas and for radon exhalation from a surface, and radon monitoring programmes. The publication also includes a case study of radon exhalation from uranium tailings pile at Jaduguda, India, and annexes presenting mathematical development of radon diffusion equations.

Research Reactors and Particle Accelerators (Applications)
Neutron Generators for Analytical Purposes
IAEA Radiation Technology Reports No. 1
This publication addresses recent developments in neutron generator (NG) technology. It presents information on compact instruments with high neutron yield, to be used for neutron activation analysis and prompt gamma neutron activation analysis in combination with high count rate spectrometers. Traditional NGs have been shown to be effective for applications including borehole logging, homeland security, nuclear medicine and the on-line analysis of aluminium, coal and cement. Pulsed fast thermal neutron analysis, as well as tagged and timed neutron analysis, are additional techniques which can be applied using NG. Furthermore, NG can be used effectively for elemental analysis and is effective for analysis of hidden materials by neutron radiography. Useful guidelines for developing NG based research laboratories are also provided in this publication.

Nuclear Analytics
Role of Nuclear Based Techniques in Development and Characterization of Materials for Hydrogen Storage and Fuel Cells
IAEA TECDOC Series No. 1676
This publication is the proceedings of a technical meeting presents an overview of the state of the art in performance testing and micro-structural characterization of recent and candidate materials for fuel cells and hydrogen storage, with a special focus on the application of nuclear techniques. The main objectives of the meeting were to support new trends in research and development programmes, to identify a methodology for application of nuclear techniques, and to strengthen international cooperation between scientists, with a special emphasis on sharing best practice and on technology transfer.
Nuclear Data for the Production of Therapeutic Radionuclides

Technical Reports Series No. 473

This publication reports the results of an IAEA coordinated research project on nuclear data for the production of therapeutic radionuclides. The aim was to provide standardized data for the production of radionuclides for therapeutic purposes, embracing current and possible future needs. Experimental data compilations, theoretical calculations and evaluations were carried out for each of the reactions. The recommendations for production of both established and emerging radionuclides are discussed, and the analysis carried out to produce the recommended data is also presented. The improved quality of the nuclear data will make reactor and accelerator production of therapeutic radionuclides much more efficient, and should also enhance their quality through improved purity of the product. The current publication includes newly evaluated data for both reactor and accelerator production of therapeutic radionuclides based on more than fifty different production reactions.

(382 pp., 88 figs; 2012) • ISBN 978-92-0-115010-3 • STI/DOC/010/473 • €75.00
URANIUM GEOLOGY, EXPLORATION AND MINING

Advances in Airborne and Ground Geophysical Methods for Uranium Exploration
IAEA Nuclear Energy Series No. NF-T-1.5

Due to growing global energy demand, many countries have seen a rise in uranium exploration activities in the past few years, and newly designed geophysical instruments and their application in uranium exploration are contributing to an increased probability of successful discoveries. This publication highlights advances in airborne and ground geophysical techniques and methods for uranium exploration, succinctly describing modern geophysical methods and demonstrating their application with examples.

(58 pp.; 2013) • ISBN 978-92-0-129010-6 • STI/PUB/1558 • €26.00

HYDROLOGY

Application of Isotope Techniques for Assessing Nutrient Dynamics in River Basins
IAEA TECDOC Series No. 1695

This publication presents the application of isotope techniques as a powerful tool for evaluating nutrient dynamics in river systems. Nutrient assessment and management in river systems has been an important part of water resource management for the past few decades, but the provision of appropriate and effective nutrient assessment and management in water resource management still remains a challenge due to the diversity of sources, pathways and transformations of nutrients. The topics discussed in this book show that the application of isotope techniques could enable or highly facilitate the examination of sources, pathways, transformations, and fates of nutrients in river systems, contributing to integrated water resource management.

(Forthcoming 2013) • ISBN 978-92-0-138810-0 • IAEA-TECDOC-1695 • €18.00

Isotope Methods for Dating Old Groundwater

This guidebook provides theoretical and practical information on using a variety of isotope tracers for dating old groundwater, i.e. water stored in geological formations for periods ranging from about 1000 to one million years. Theoretical underpinnings of the methods and guidelines for their use in different hydrogeological environments are described. The guidebook also presents a number of case studies providing insight into how various isotopes have been used in aquifers around the world. The methods, findings and conclusions presented in this publication will enable students and practicing groundwater scientists to evaluate the use of isotope dating tools for specific issues related to the assessment and management of groundwater resources. In addition, the guidebook will be of use to the scientific community interested in issues related to radioactive waste disposal in geological repositories.

(357 pp.; 178 figs; 2013) • ISBN 978-92-0-137210-9 • STI/PUB/1587 • €70.00

Isotopes in Hydrology, Marine Ecosystems and Climate Change Studies
Proceedings of an International Symposium held in Monaco, 27 March–1 April 2011
Proceedings Series

This publication presents the proceedings of the latest IAEA symposium on isotopes in hydrology, marine ecosystems and climate change studies. At the symposium, five major topics were addressed through invited talks and oral presentations. These five sessions covered: the role of isotopes in understanding and modelling climate change, marine ecosystems and the water cycle; carbon dioxide sequestration and related aspects of the carbon cycle, such as ocean acidification; isotopes and radionuclides in the marine environment, groundwater assessments for large aquifers; analytical methods and instrumentation for the application of isotopes in environmental, climate and hydrological studies. Leading scientists in the field of climate change and hydrology, as well as representatives from climate change and environmental bodies and organizations, exchanged their views and experience.

(Forthcoming 2013) • ISBN 978-92-0-135610-9 • STI/PUB/1580 • €90.00

Monitoring Isotopes in Rivers: Creation of the Global Network of Isotopes in Rivers (GNIR)
IAEA TECDOC Series No. 1673

This publication presents and evaluates several isotope datasets compiled in a number of recently established river monitoring stations founded at the time of the creation of the Global Network of Isotopes in Rivers (GNIR). It also contains the preliminary results from 12 field sites now included in GNIR. These studies illustrate the different hydrological aspects of river basins that can be addressed by regular monitoring of environmental isotopes in rivers. The target readers for this publication are hydrologists, hydrogeologists and isotope experts dealing with catchment hydrology and management of water resources, as well as technical cooperation project counterparts in Member States.

Design, Development and Optimization of a Low-cost System for Digital Industrial Radiology

IAEA Radiation Technology Reports No. 2

Systems for digital industrial radiology are currently quite expensive and, therefore, often unaffordable for most of the institutes and non-destructive testing groups in developing Member States. This publication provides guidance on the development of such systems at a relatively lower cost. The aims are to facilitate the acquisition of state of the art digital technology, which has tremendous potential for enhancing the speed as well as the quality of radiographic inspection, in the long run ensuring the quality of industrial equipment and components.

(Forthcoming 2013) • ISBN 978-92-0-129310-7 • STI/PUB/1561 • €40.00

Development of Novel Adsorbents and Membranes by Radiation-induced Grafting for Selective Separation in Environmental and Industrial Applications

IAEA Radiation Technology Reports No. 3

This publication summarizes the results of a coordinated research project on the development of novel adsorbents and membranes by radiation-induced grafting for selective separation purposes. Radiation-induced grafting is a technique that uses readily available, low cost synthetic and natural polymers to prepare novel materials for use where the requirements for bulk properties and surface properties cannot be readily met using a single polymeric material. The objective of the coordinated research project was to use gamma rays, electron beams and swift heavy ions to graft various monomers onto natural and synthetic polymers for the development of novel adsorbents and membranes for environmental and industrial applications. The publication provides a summary of the project results and includes reports by the participants.

(278 pp., 285 figs; 2012) • ISBN 978-92-0-134010-8 • STI/PUB/1572 • €18.00

RADIATION PROCESSING

Guidelines for Development, Validation and Routine Control of Industrial Radiation Processes

IAEA Radiation Technology Series No. 4

Quality assurance is vital for the success of radiation technologies and requires the development of standardized procedures and the harmonization of process validation and control. The guidelines in this publication have been developed based on requests from Member States to provide guidance on fulfilling the requirements of the International Standard for Development, Validation and Routine Control for a Radiation Process, published by the International Organization for Standardization (ISO). While the ISO standard was developed for the sterilization of healthcare products, the present guidelines are generalized and are therefore relevant to any radiation process. This is possible since the principles involved in regulating a radiation process for achieving quality products are generally the same for any product or application. In several places, additional information has been included to provide insight into the radiation process that could help irradiator operators and their quality managers to provide better service to their customers.

(Forthcoming 2013) • ISBN 978-92-0-135710-6 • STI/PUB/1581 • €29.00

Neutron Transmutation Doping of Silicon at Research Reactors

IAEA TECDOC Series No. 1681

This publication details the processes and history of neutron transmutation doping of silicon, particularly its commercial pathway, followed by the requirements for a technologically modern and economically viable production scheme and the current trends in the global market for semiconductor products. It provides guidance on the technical requirements, involved processes and required quality standards for the transmission of sound practices as well as advice for research reactor managers and operators planning commercial scale production of silicon. Furthermore, a detailed and specific database of most of the world’s research reactor facilities in this domain is included, featuring their irradiation capabilities, associated production capacities and processing.


TRACERS

Application of Radiotracer Techniques for Interwell Studies

IAEA Radiation Technology Series No. 3

The main purpose of interwell tracer tests in oil and geothermal reservoirs is to monitor qualitatively and quantitatively the injected fluid connections between injection and production wells and to provide important data for better understanding of the reservoir geology in order to optimize the production strategy and thereby maximize the oil recovery or thermal energy production. Most of the information given by the radiotracer tests cannot be obtained by other means. Based on the key findings of an IAEA coordinated research project in this area, this publication describes the principles and the state of the art of radiotracer techniques for interwell investigations and provides practical guidance on the design and implementation
of tracer experiments as well as on the interpretation of the results.

(231 pp., 122 figs; 2012) • ISBN 978-92-0-125610-2 • STI/PUB/1539 • €54.00

Radiotracer Generators for Industrial Applications
IAEA Radiation Technology Series No. 5

This publication, which draws on the outcome of an IAEA coordinated research project and on input from experts in the field, provides a unique source of information pertaining to the development of radiotracer generators and their use in troubleshooting and optimizing industrial processes. It describes the results of research undertaken in the characterization of $^{68}$Ge/$^{68}$Ga, $^{137}$Cs/$^{137m}$Ba, $^{99}$Mo/$^{99m}$Tc and $^{113}$Sn/$^{113m}$In radiotracer generators and their validation in industrial process investigations. Looking at trends in the industrialization process of developing countries, there is evidence that radiotracer techniques will continue to play an important role in industry for many years to come, and the findings of this research project will help Member States to make larger use of radiotracer technology for problem resolution in industry and environment.

(203 pp., 96 figs; 2013) • ISBN 978-92-0-135410-5 • STI/PUB/1579 • €34.00
This publication provides guidance specific to nuclear facilities on implementing a computer security programme and evaluating existing programmes. The use of computer systems to cover an increasing range of functions at nuclear facilities introduces new vulnerabilities that could seriously endanger nuclear security if not addressed in a rigorous and balanced manner. Digital systems are increasingly being introduced in safety, safety related and security systems throughout facilities. Non-availability or malfunction of these systems can seriously impact nuclear safety and security, and potentially facilitate sabotage of the facility and/or theft of material. Computer security must, therefore, be a key component of overall facility security.

IAEA TECDOC Series No. 1678
This publication provides a detailed overview of the results and achievements of the IAEA’s EMRAS (Environmental Modelling for Radiation Safety) programme, which ran from 2003 to 2007. The activities of the various working groups focused on the compilation of a handbook of parameter values for the prediction of radionuclide transfer in temperate environments, on the testing and comparison of models to assess the transfer of tritium and 14C to biota and humans, on the validation of models for dose reconstruction due to 131I after the Chernobyl accident, on modelling the transfer of radionuclides in aquatic systems, on remediation of rural and urban sites with radioactive residues, and on the impact of environmental radioactivity on non-human species. The book concludes with a summary of the outcomes of the EMRAS programme and is accompanied by a CD-ROM which provides details of the work and the results of the working groups.

Establishing the Nuclear Security Infrastructure for a Nuclear Power Programme
IAEA Nuclear Security Series No. 19
This publication provides guidance on the actions that should be taken by a State to implement an effective nuclear security infrastructure for a nuclear power programme. The topics covered are: development of national policy and strategy, common nuclear security measures, infrastructure issues relating to nuclear and other radioactive material, associated facilities and cooperation with other States. The guidance provided is intended primarily for use by national policy makers, national legislators, competent authorities, institutions and individuals that are involved in the establishment, implementation, maintenance or sustainability of the nuclear security infrastructure for a nuclear power programme.

Establishing the Safety Infrastructure for a Nuclear Power Programme
Specific Safety Guide
IAEA Safety Standards Series No. SSG-16
This Safety Guide provides guidance on the establishment of a national nuclear safety infrastructure as a key component of the overall preparations required for emerging nuclear power programmes. It provides recommendations, presented in the form of 200 sequential actions, on meeting the applicable IAEA safety requirements during the first three phases of the development of a nuclear power programme. It is intended for use by persons or organizations participating in the preparation and implementation of a nuclear power programme, including government officials and legislative bodies, regulatory bodies, operating organizations and external support entities.

Contents: 1. Introduction; 2. Implementing IAEA general safety requirements for the establishment of the safety infrastructure; 3. Implementing the IAEA specific safety requirements for the establishment of the safety infrastructure; Appendix: Overview of actions to be taken in each phase for the establishment of safety infrastructure.
Identification of Vital Areas at Nuclear Facilities
IAEA Nuclear Security Series No. 16

This publication provides detailed guidance with regard to the identification of vital areas at nuclear facilities. It presents a structured approach to identifying those areas that contain equipment, systems and components to be protected against sabotage. The process for selection of a specific set of vital areas to be protected is based on consideration of the potential radiological consequences of sabotage, and on the design, operational and safety features of a nuclear facility. The method builds upon safety analysis to develop logic models for sabotage scenarios that could cause unacceptable radiological consequences. The sabotage actions represented in the logic models are linked to the areas from which they can be accomplished. The logic models are then analysed to determine areas that should be protected to prevent these unacceptable radiological consequences. The publication is part of a set of supporting publications in the IAEA Nuclear Security Series with the aim of assisting States in the design, implementation and evaluation of their physical protection systems for nuclear material and nuclear facilities.

(37 pp., 2 figs; 2012) • ISBN 978-92-0-114410-2 • STI/PUB/1505 • €22.00

Licensing the First Nuclear Power Plant
INSAG Series No. 26

A robust national nuclear safety infrastructure is essential for the deployment of a country’s first nuclear power plant. A major challenge in this process is the development of an effective legal and governmental framework for safety, including an independent regulatory body. This publication supplements existing guidance in the IAEA safety standards on the development of an effective safety infrastructure and provides further assistance to new entrant regulatory bodies on the key challenges they will face throughout the life cycle of the first nuclear power plant. The publication focuses on the phases of a nuclear power deployment programme from the granting of a licence for construction to granting the licence for commissioning and operation.

(49 pp., 1 fig; 2012) • ISBN 978-92-0-134210-2 • STI/PUB/1573 • €25.00

Management System Standards: Comparison between IAEA GS-R-3 and ASME NQA-1-2008 and NQA-1a-2009 Addenda
Safety Reports Series No. 70

This Safety Report compares the requirements of IAEA Safety Standards Series No. GS-R-3, The Management System for Facilities and Activities, and the American Society of Mechanical Engineers (ASME) Quality Assurance Requirements for Nuclear Facility Applications (ASME NQA-1-2008, NQA-1a-2009). It identifies the similarities and differences between them and provides information and guidance to assist an organization in meeting the requirements of both standards.

(61 pp.; 2012) • ISBN 978-92-0-120810-1 • STI/PUB/1530 • €29.00

Management System Standards: Comparison between IAEA GS-R-3 and ISO 9001:2008
Safety Reports Series No. 69

This Safety Report compares the requirements of IAEA Safety Standards Series No. GS-R-3, The Management System for Facilities and Activities, and ISO 9001:2008, Quality Management Systems — Requirements, and identifies the main differences between the two standards. It provides information and guidance on adding safety specific management system requirements to the ISO 9001:2008 standard, to ensure that safety can be achieved. The publication is intended primarily for use by owners, operators and employees of nuclear facilities and installations, and by regulatory bodies, suppliers, and research and development organizations.

(55 pp., 1 fig; 2012) • ISBN 978-92-0-120710-4 • STI/PUB/1529 • €29.00

Monitoring for Compliance with Remediation Criteria for Sites
Safety Reports Series No. 72

This Safety Report provides detailed and practical advice to operators and regulators on the development and implementation of monitoring strategies in order to demonstrate compliance with radiological criteria for release of sites for unrestricted or restricted use. The publication complements the IAEA Safety Report on monitoring for compliance with exemption and clearance levels, which applies to clearance of bulk material from regulatory control.

(190 pp., 49 figs; 2012) • ISBN 978-92-0-127910-1 • STI/PUB/1551 • €40.00

Nuclear Security Recommendations on Nuclear and Other Radioactive Material out of Regulatory Control
IAEA Nuclear Security Series No. 15

This publication presents recommendations for the nuclear security of nuclear and other radioactive material that is out of regulatory control. It is based on national experience and practices and guidance publications in the field of security as well as the nuclear security related international instruments. The recommendations include guidance for States with regard to the nuclear security of nuclear and other radioactive material that has been reported as being out of regulatory control as well as of material that is...
lost, missing or stolen but has not been reported as such, or has been otherwise discovered. In addition, these recommendations adhere to the detection and assessment of alarms and alerts and to a graded response to criminal or unauthorized acts with nuclear security implications.

English Edition (33 pp.; 2011) • ISBN 978-92-0-112210-0 • STI/PUB/1488 • €23.00

Nuclear Security
Recommendations on Radioactive Material and Associated Facilities
IAEA Nuclear Security Series No. 14

The purpose of this publication is to provide guidance to States and competent authorities on how to develop or enhance, implement and maintain a nuclear security regime for facilities dealing with radioactive material and associated activities. This is to be achieved through the establishment or improvement of their capabilities to implement a legislative and regulatory framework to address the security of radioactive material, associated facilities and associated activities in order to reduce the likelihood of malicious acts involving those materials. These recommendations reflect a broad consensus among States on the requirements which should be met for the security of radioactive material, associated facilities and activities.


Nuclear Security Systems and Measures for Major Public Events
IAEA Nuclear Security Series No. 18

This publication provides an overview, based on practical experience and lessons learned, for establishing nuclear security systems and measures for major public events. It covers technical and administrative nuclear security measures for developing the necessary organizational structure, developing plans, strategies and concepts of operations, and making arrangements for implementing the developed plans, strategies and concepts.

(56 pp., 14 fgs; 2012) • ISBN 978-92-0-127010-8 • STI/PUB/1546 • €30.00

Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards
General Safety Requirements
IAEA Safety Standards Series No. GSR Part 3

This publication is the new edition of the International Basic Safety Standards. This edition is co-sponsored by seven other international organizations — European Commission (EC/ Euratom), FAO, ILO, OECD/NEA, PAHO, UNEP and WHO. It replaces the interim edition that was published in November 2011. The previous edition of the International Basic Safety Standards was published in 1996. It has been extensively revised and updated to take account of the latest finding of the United Nations Scientific Committee on the Effects of Atomic Radiation, and the latest recommendations of the International Commission on Radiological Protection. The publication details the requirements for the protection of people and the environment from harmful effects of ionizing radiation and for the safety of radiation sources. All circumstances of radiation exposure are considered.

(Forthcoming 2013) • ISBN 978-92-0-135310-8 • STI/PUB/1578 • €62.00

Safety Culture in Pre-operational Phases of Nuclear Power Plant Projects
Safety Reports Series No. 74

An abundance of information exists on safety culture related to the operational phases of nuclear power plants, however, pre-operational phases present unique challenges. This publication focuses on safety culture during pre-operational phases, which span the interval from before a decision is taken to launch a nuclear power programme to first fuel load. It provides safety culture insights and focuses on eight generic issues: safety culture understanding; multicultural aspects; leadership; competencies and resource competition; management systems; learning and feedback; cultural assessments; and communication. Each issue is discussed in terms of: specific challenges; desired state; approaches and methods; and examples and resources. This publication will be of interest to newcomers and experienced individuals faced with the opportunities and challenges inherent in safety culture programmes aimed at pre-operational activities.

(69 pp., 6 fgs; 2012) • ISBN 978-92-0-128710-6 • STI/PUB/1555 • €31.00
components of operating experience feedback systems, utilizing relevant information on events and abnormal conditions that have occurred at nuclear installations around the world. It focuses on the interaction between the different systems for using operating experience feedback and constitutes an update and an extension of Part I: A National System, of Systems for Reporting Unusual Events in Nuclear Power Plants (IAEA Safety Series No. 93).

Contents: 1. Introduction; 2. Main elements of a national system for the feedback of operational experience; 3. Screening of events; 4. Investigation and analysis of events; 5. Corrective actions; 6. Trending and review to recognize emergent problems; 7. Utilization, dissemination and exchange of information on operating experience; 8. Reviewing the effectiveness of the process for feedback of operational experience; 9. Quality assurance; 10. Reporting of safety related events; Appendix I: Reporting criteria and categories; Appendix II: Types of event report, timing, format and content; Appendix III: Investigation and analysis of events; Appendix IV: Approval and implementation of corrective actions; Annex I: Data management for the feedback of operating experience; Annex II: Example of elements of a national feedback system for operating experience.

English Edition (61 pp., 1 fig.; 2006) • ISBN 978-92-0-101406-6 • STI/PUB/1243 • €23.00

Commissioning for Nuclear Power Plants

Specific Safety Guide

IAEA Safety Standards Series No. SSG-28

This Safety Guide provides recommendations on the basis of international best practices, as currently followed in IAEA Member States, on how to meet the requirements for the commissioning for nuclear power plants. These requirements enable the commissioning of a nuclear power plant to proceed safely and to a high quality. The recommendations will also enable the necessary assurances to be provided that the plant has been constructed in accordance with the design intent and can be operated safely.

(Forthcoming 2013) • ISBN 978-92-0-140110-6 • STI/PUB/1595 • €30.00

Conduct of Operations at Nuclear Power Plants

Safety Guide

IAEA Safety Standards Series No. NS-G-2.14

This Safety Guide identifies the main responsibilities and practices of nuclear power plant operations departments in relation to their responsibility for the safe functioning of the plant. The guide presents the factors to be considered in structuring the operations department of a nuclear power plant; setting high standards of performance; making safety related decisions in an effective manner; conducting control room and field activities in a thorough and professional manner; and maintaining a nuclear power plant within established operational limits and conditions.


Deterministic Safety Analysis for Nuclear Power Plants

Specific Safety Guide

IAEA Safety Standards Series No. SSG-2

The objective of this Safety Guide is to provide harmonized guidance to designers, operators, regulators and providers of technical support on deterministic safety analysis for nuclear power plants. It provides information on the utilization of the results of such analysis for safety and reliability improvements. The Safety Guide addresses conservative, best estimate and uncertainty evaluation approaches to deterministic safety analysis and is applicable to current and future designs.


Engineering Safety Aspects of the Protection of Nuclear Power Plants against Sabotage

IAEA Nuclear Security Series No. 4

This report provides guidelines for evaluating the engineering safety aspects of the protection of nuclear power plants against sabotage. The guidance, which is the result of extensive dialogue among safety and security specialists, takes into account the existing robustness of structures, systems and components and emphasizes those aspects of sabotage protection that work synergistically with the protection against extreme external occurrences of accidental origin, such as earthquakes, tornadoes and human induced events. The report introduces a defence in depth approach to sabotage protection, with layers comprising safety and security related systems and activities, and promotes self-assessment by the licensee in cooperation with the required interfaces with the competent authorities.

English Edition (58 pp., 1 fig.; 2007) • ISBN 92-0-109906-1 • STI/PUB/1271 • €30.00

Low Level Event and Near Miss Process for Nuclear Power Plants: Best Practices

Safety Reports Series No. 73

This publication provides nuclear power plant operators and regulatory organizations with a best practice overview of the development, implementation and continuous improvement of low level events and near miss processes. Use of guidance and best practices, as described in this publication, will help the relevant organizations in recognizing emerging adverse trends by analysing lower level events and near misses. Correcting such adverse trends proactively may prevent occurrence of significant events, and thereby, enhance the safety and reliability of nuclear power plants.

(86 pp., 13 figs; 2012) • ISBN 978-92-0-126610-1 • STI/PUB/1545 • €30.00

Periodic Safety Review for Nuclear Power Plants

Specific Safety Guide

IAEA Safety Standards Series No. SSG-25

This Safety Guide provides recommendations and guidance on conducting periodic safety review (PSR) of an existing nuclear power plant. PSR is a comprehensive safety review of all important aspects of safety, carried out at regular intervals, typically every ten years. In addition, PSR may be used in support of the decision making process for licence renewal or long term operation, or for restart of a nuclear power plant following a prolonged shutdown. The review process described in this Safety Guide is valid for nuclear power plants of any age and may have a wider applicability, for example to research reactors and radioactive waste management facilities, by means of a graded approach. Although PSR may not be an appropriate means for identifying safety issues in the decommissioning phase, the documentation resulting from PSR of an operating nuclear power plant will be an important input when planning decommissioning.

(106 pp.; 2013) • ISBN 978-92-0-137410-3 • STI/PUB/1588 • €37.00

Safety of Nuclear Power Plants: Commissioning and Operation

Specific Safety Requirements

IAEA Safety Standards Series No. SSR-2/2

This publication is a revision of IAEA Safety Standards Series No. NS-R-2, Safety of Nuclear Power Plants: Operation, and has been extended to cover the commissioning stage. It describes the requirements to be met to ensure the safe operation of nuclear power plants. Over recent years there have been developments in areas such as long term operation, plant ageing, periodic safety review, probabilistic safety analysis and risk informed decision making processes. It became necessary to revise the IAEA’s safety requirements in these areas and to correct and/or improve the publication on the basis of feedback from its application by both the IAEA and its Member States. In addition, the requirements are governed by, and must apply, the safety objective and safety principles that are established in the Fundamental Safety Principles (IAEA Safety Standards Series No. SF-1).

Contents: 1. Introduction; 2. Safety objectives and principles; 3. The management and organizational structure of the operating organization; 4. Management of operational safety; 5. Operational safety programmes; 6. Plant commissioning;...


Arabic Edition (38 pp.; 2011) • ISBN 978-92-0-618510-0 • STI/PUB/1252 • €25.00
English Edition (27 pp.; 2006) • ISBN 92-0-106506-X • STI/PUB/1252 • €25.00

Volcanic Hazards in Site Evaluation for Nuclear Installations

Specific Safety Guide
IAEA Safety Standards Series No. SSG-21
This publication provides comprehensive and updated guidance for site evaluation in relation to volcanic hazards. It includes recommendations on assessing the volcanic hazards at a nuclear installation site, in order to identify and characterize, in a comprehensive manner, all potentially hazardous phenomena that may be associated with future volcanic events. It describes how some of these volcanic phenomena may affect the acceptability of the selected site, resulting in exclusion of a site or determining the corresponding design basis parameters for the installation. This Safety Guide is applicable to both existing and new sites, and a graded approach is recommended to cater for all types of nuclear installation.
(106 pp.; 2 figs; 2012) • ISBN 978-92-0-128110-4 • STI/PUB/1552 • €30.00

RESEARCH REACTORS

IAEA TECDOC Series No. 1705
This publication is the final report of the INPRO collaborative project on advanced water cooled reactor (AWCR) case studies in support of passive safety systems. It compiles case study results on natural circulation and thermal stratification
Implementation of a Management System for Operating Organizations of Research Reactors

Safety Reports Series No. 75
The requirements for management systems for research reactors are set out in the IAEA safety standards. To ensure that an integrated management system based on the IAEA safety standards is tailored for the size of the different organizations and commensurate to the risks of an activity, the safety requirements for management systems for facilities and activities (IAEA Safety Standards Series No. GS-R-3) includes a requirement to grade the application of the management system and the deployment of resources appropriately. This publication not only applies the relevant standards and presents the processes for larger operating organizations of research reactors to ensure safe operation and utilization, but it also provides a case study of a graded approach to the application of the management system requirements as implemented by a small research reactor. This report will be useful for research reactor operating organizations, particularly those intending to implement a process based integrated management system, and may also be of interest to other nuclear facilities and to regulatory bodies.

(Forthcoming 2013) • ISBN 978-92-0-139810-9 • IAEA-TECDOC-1705 • €18.00

Research Reactors: Safe Management and Effective Utilization

Proceedings of an International Conference, held in Rabat, Morocco, 14–18 November 2011
Proceedings CD Series
This CD-ROM contains the proceedings of the fourth international conference on research reactors, convened to promote the exchange of information on research reactor issues and trends among users, operators, regulators, designers and suppliers. The conference included more than 120 oral and poster presentations pertaining to six technical areas of research reactors: utilization and applications; operation and maintenance; new research reactor projects; safety; spent fuel, waste and decommissioning; reactor designers and providers. The information provided on this CD-ROM will serve as a reference for today’s international research reactor community in terms of its achievements, issues and challenges to date, as well as future trends and anticipated developments.


Safety Assessment for Research Reactors and Preparation of the Safety Analysis Report
Specific Safety Guide
IAEA Safety Standards Series No. SSG-20
This publication provides guidance on performing safety assessments throughout the lifetime of a research reactor and on the regulatory review of this assessment within the framework of the licensing process. Guidance on preparation of the safety analysis report, including its format and contents, is also provided.

Contents: 1. Introduction; 2. Safety assessment in the licensing process; 3. Preparation of the safety analysis report; 4. Information to be submitted for the review and assessment process; Appendix: Content of a safety analysis report; Annex I: Approach to and methods of safety analysis; Annex II: Examples of input parameters and initial conditions; Annex III: Items to be considered in the description of the research reactor; Annex IV: Typical radiation sources and radiation fields in a research reactor.

(118 pp., 2 figs; 2012) • ISBN 978-92-0-115410-1 • STI/PUB/1508 • €35.00

Safety in the Utilization and Modification of Research Reactors
Specific Safety Guide
IAEA Safety Standards Series No. SSG-24
This Safety Guide is a revision of IAEA Safety Series No. 35-G1, and experience acquired from the use of that Safety Guide has been taken into account. The present publication provides guidance on performing safety assessments throughout the lifetime of a research reactor and on the regulatory review of this assessment within the framework of the licensing process. Guidance on preparation of the safety analysis report, including its format and contents, is also provided.

Contents: 1. Introduction; 2. Management system for the utilization and modification of a research reactor; 3. Categorization, safety assessment and approval of an experiment or modification; 4. Safety considerations in different phases of utilization and modification projects; 5. Pre-implementation
phase of a modification or utilization project; 6. Implementation phase of a modification or utilization project; 7. Post-implementation phase of a utilization or modification project; 8. Operational safety of experiments at a research reactor; 9. Safety considerations in the handling, dismantling, post-irradiation examination and disposal of experimental devices; 10. Safety aspects of out-of-reactor-core installations; Annex I: Example of a checklist for the categorization of an experiment or modification at a research reactor; Annex II: Example of the content of the safety analysis report for an experiment at a research reactor; Annex III: Examples of reasons for a modification at a research reactor.

(68 pp., 3 figs; 2012) • ISBN 978-92-0-129110-3 • STI/PUB/1559 • €28.00

**Use of a Graded Approach in the Application of the Safety Requirements for Research Reactors**

*Specific Safety Guide*

IAEA Safety Standards Series No. SSG-22

This publication provides recommendations on the appropriate manner to comply with the safety requirements for research reactors, IAEA Safety Standards Series No. NS-R-4, utilizing a graded approach. It is intended for use by operating organizations, regulatory bodies and other organizations involved in the design, construction and operation of research reactors.


(74 pp., 2 figs; 2012) • ISBN 978-92-0-127310-9 • STI/PUB/1547 • €29.00

**Control of Orphan Sources and Other Radioactive Material in the Metal Recycling and Production Industries**

*Specific Safety Guide*

IAEA Safety Standards Series No. SSG-17

Accidents involving orphan sources and other radioactive material in the metal recycling and production industries have resulted in serious radiological accidents as well as in harmful environmental, social and economic impacts. This Safety Guide provides recommendations, the implementation of which should prevent such accidents and provide confidence that scrap metal and recycled products are safe.


(82 pp., 3 figs; 2012) • ISBN 978-92-0-115510-8 • STI/PUB/1509 • €31.00

**Criticality Safety in the Handling of Fissile Material**

*Specific Safety Guide*

IAEA Safety Standards Series No. SSG-27

This Safety Guide provides guidance and recommendations on how to meet the relevant requirements for ensuring subcriticality when dealing with fissile material and for planning the response to criticality accidents. The guidance and recommendations are applicable to both regulatory bodies and operating organizations. The objectives of criticality safety are to prevent a self-sustained nuclear chain reaction and to minimize the consequences of this if it were to occur. The Safety Guide makes recommendations on how to ensure subcriticality in systems involving fissile materials during normal operation, anticipated operational occurrences, and, in the case of accident conditions, within design basis accidents, from initial design through commissioning, operation, and decommissioning and disposal.

(Forthcoming 2013) • ISBN 978-92-0-140010-9 • STI/PUB/1594 • €28.00

**National Strategy for Regaining Control over Orphan Sources and Improving Control over Vulnerable Sources**

*Specific Safety Guide*

IAEA Safety Standards Series No. SSG-19

This Safety Guide is intended to provide recommendations on the establishment of a national strategy for regaining control over orphan radioactive sources and for improving control over vulnerable radioactive sources. It provides guidance on how to assess the national situation, and develop and implement a national strategy to achieve these goals.

Contents: 1. Introduction; 2. Assessing the problem; 3. Development of the national strategy; 4. Implementation phase of a utilization or modification project; 5. Post-implementation phase of a utilization or modification project; 8. Operational safety of experiments at a research reactor; 9. Safety considerations in the handling, dismantling, post-irradiation examination and disposal of experimental devices; 10. Safety aspects of out-of-reactor-core installations; Annex I: Example of a checklist for the categorization of an experiment or modification at a research reactor; Annex II: Example of the content of the safety analysis report for an experiment at a research reactor; Annex III: Examples of reasons for a modification at a research reactor.

(82 pp., 3 figs; 2012) • ISBN 978-92-0-115510-8 • STI/PUB/1509 • €31.00
TRANSPORT OF RADIOACTIVE MATERIAL


Safety Guide

IAEA Safety Standards Series No. TS-G-1.6 (Rev. 1)

This Safety Guide is issued in support of Regulations for the Safe Transport of Radioactive Material (IAEA Safety Standards Series No. TS-R-1, 2009 Edition). It lists the paragraph numbers of the Transport Regulations that are relevant for specified types of consignment, classified according to their UN numbers. It does not provide additional recommendations. The intended users are consignors and consignees, carriers, shippers, regulators, and end users involved in the transport of radioactive material. A person or organization intending to transport a particular type of consignment of radioactive material must meet requirements in all sections of the Transport Regulations. This Safety Guide aids users by providing a listing of the relevant requirements of the Transport Regulations for each type of radioactive material, package or shipment. Once a consignor has classified the radioactive material to be shipped, the appropriate UN number can be assigned and the paragraph numbers of the requirements that apply for the shipment can be found in the corresponding schedule.

(Forthcoming 2013) • ISBN 978-92-0-192510-7 • STI/PUB/1614 • €20.00


Specific Safety Guide

IAEA Safety Standards Series No. SSG-26

This Safety Guide provides recommendations and guidance on achieving and demonstrating compliance with IAEA Safety Standards Series No. SSR-6, Regulations for the Safe Transport of Radioactive Material (2012 Edition), which establishes the requirements to be applied to the national and international transport of radioactive material. Transport is deemed to comprise all operations and conditions associated with and involved in the movement of radioactive material, including the design, fabrication and maintenance of packaging, and the preparation, consigning, handling, carriage, storage in transit and receipt at the final destination of packages. This publication supersedes IAEA Safety Standards Series No. TS-G-1.1 Rev. 1, which was issued in 2008.

(Forthcoming 2013) • ISBN 978-92-0-136910-9 • STI/PUB/1586 • €58.00

Regulations for the Safe Transport of Radioactive Material — 2012 Edition

Specific Safety Requirements

IAEA Safety Standards Series No. SSR-6

This publication establishes the regulations that apply to the transport of radioactive material by all modes of transport on land, water or in the air, including transport that is incidental to the use of the radioactive material. The objective and scope of the regulations are described in detail as well as the range of their application. The publication provides requirements useful to governments, regulators, operators of nuclear facilities, carriers, users of radiation sources and cargo handling personnel.

Contents: 1. Introduction; 2. Definitions; 3. General provisions; 4. Activity limits and classification; 5. Requirements and controls for transport; 6. Requirements for radioactive materials and for packagings and packages; 7. Test procedures; 8. Approval and administrative requirements; Annex I: Summary of approval and prior notification requirements; Annex II: Conversion factors and prefixes; Annex III: Summary of consignments requiring exclusive use. (Formerly known as TS-R-1)

Arabic Edition (177 pp.; 7 figs; 2013) • ISBN 978-92-0-638410-7 • STI/PUB/1570 • €44.00
Chinese Edition (164 pp.; 7 figs; 2013) • ISBN 978-92-0-538110-7 • STI/PUB/1570 • €44.00
English Edition (168 pp.; 7 figs; 2012) • ISBN 978-92-0-133310-0 • STI/PUB/1570 • €44.00
French Edition (174 pp.; 7 figs; 2013) • ISBN 978-92-0-238910-6 0 • STI/PUB/1570 • €44.00
Russian Edition (Forthcoming 2013)
Spanish Edition (Forthcoming 2013)


Safety Guide

IAEA Safety Standards Series No. TS-G-1.6

Since 1961, IAEA Transport Regulations have been used worldwide by industry, competent authorities and international organizations. While the provisions of the Regulations are essentially clear and unambiguous, they are often also highly technical in nature and unavoidably complex. Therefore, there is a need for this publication, which supplements the Regulations by providing specific information on individual consignments, to help users to identify the applicable requirements. It assists users in complying with the safety standards prescribed in the IAEA Transport Regulations (IAEA Safety Standards Series No. SSR-6).

Contents: 1. Introduction; 2. Definitions and classification; Schedules.

Radiation Protection

Radiation Protection and Management of NORM Residues in the Phosphate Industry
Safety Reports Series No. 78

This Safety Report is a compilation of detailed information on the processes and materials associated with the phosphate industry and on the radiological considerations that need to be taken into account by the regulatory body when determining the nature and extent of radiation protection measures. It has been developed as part of the IAEA's programme on the application of its safety standards in the field of radiation, transport and waste safety. The information provided will assist in the implementation of a graded approach to regulation, in terms of which the application of the requirements of the safety standards is commensurate with the characteristics of the practice or source and with the magnitude and likelihood of the exposures. The publication also provides information on expected radionuclide concentrations, exposure levels and the most appropriate regulatory approach in the phosphate industry, and covers the mining and beneficiation of phosphate ore, phosphoric acid production, phosphogypsum, and the manufacture and use of phosphatic fertilizers among others. (288 pp., 90 figs; 2013) • ISBN 978-92-0-135810-3 • STI/PUB/1582 • €55.00

Radiation Protection in Paediatric Radiology
Safety Reports Series No. 71

This publication provides guidance to radiologists, other clinicians and radiographers/technologists involved in diagnostic procedures using ionizing radiation with children and adolescents, and should also be of value to medical physicists and regulators. It focuses on the measures necessary to provide protection from the effects of radiation using the principles established in the IAEA's International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (IAEA Safety Standards No. GSR Part 3 (Interim)), and the priority accorded to the area. The emphasis throughout is on the special requirements of paediatrics. (111 pp., 2 figs; 2012) • ISBN 978-92-0-125710-9 • STI/PUB/1543 • €38.00

Radiation Safety in Industrial Radiography
Specific Safety Guide
IAEA Safety Standards Series No. SSG-11


Arabic Edition (105 pp., 2 figs; 2012) • ISBN 978-92-0-633110-1 • STI/PUB/1466 • €33.00
English Edition (104 pp., 2 figs; 2011) • ISBN 978-92-0-107210-8 • STI/PUB/1466 • €33.00
French Edition (112 pp., 2 figs; 2013) • ISBN 978-92-0-236610-7 • STI/PUB/1466 • €33.00
Spanish Edition (Forthcoming 2013)
Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency

General Safety Guide
IAEA Safety Standards Series No. GSG-2

This Safety Guide presents a coherent set of generic criteria (expressed numerically in terms of radiation dose) that form a basis for developing the operational levels needed for decision making concerning protective and response actions. The set of generic criteria addresses the requirements established in IAEA Safety Standards Series No. GS-R-2 for emergency preparedness and response, including lessons learned from responses to past emergencies, and provides an internally consistent foundation for the application of radiation protection. The publication also proposes a basis for a plain language explanation of the criteria for the public and for public officials.

Contents: 1. Introduction; 2. Basic considerations; 3. Framework for emergency response criteria; 4. Guidance values for emergency workers; 5. Operational criteria; Appendix I: Dose concepts and dosimetric quantities; Appendix II: Examples of default oils for deposition, individual monitoring and contamination of food, milk and water; Appendix III: Development of EALs and example EALs for light water reactors; Appendix IV: Observables at the scene of a nuclear or radiological emergency.

Disposal of Radioactive Waste
Specific Safety Requirements
IAEA Safety Standards Series No. SSR-5

This publication establishes requirements applicable to all types of radioactive waste disposal facility. It is linked to the fundamental safety principles for each disposal option and establishes a set of strategic requirements that must be in place before facilities are developed. Consideration is also given to the safety of existing facilities developed prior to the establishment of present-day standards. The requirements will be complemented by Safety Guides that will provide guidance on good practice for meeting the requirements for different types of waste disposal facility.


Monitoring for Compliance with Exemption and Clearance Levels

Safety Reports Series No. 67

Radioactive material is present in the environment and is also generated during the operation and subsequent decommissioning of facilities that have used or produced radioactive material. Particularly during decommissioning, a large amount of material may be generated that is below the activity limits requiring regulatory control. This Safety Report focuses on the development and practical implementation of strategies for demonstrating compliance with the established exemption and clearance levels. It provides valuable information for operators, regulatory bodies and other organizations that are involved in the monitoring of material for its release from regulatory control.

Monitoring for Compliance with Remediation Criteria for Sites

Safety Reports Series No. 72

This Safety Report provides detailed and practical advice to operators and regulators on the development and implementation of monitoring strategies in order to demonstrate compliance with radiological criteria for release of sites for unrestricted or restricted use. The publication complements the IAEA Safety Report on monitoring for compliance with exemption and clearance levels (Safety Reports Series No. 67), which applies to clearance of bulk material from regulatory control.

Peer Review of the Radioactive Waste Management Activities of COVRA, Netherlands

IAEA Safety Standards Application Series No. 8

This publication presents the outcome of a peer review of the overall waste management programme within the Netherlands, whose programme has been carefully formulated for the particular circumstances of a country with a limited nuclear power industry, albeit with prospects for some
expansion. The Netherlands has opted for long term storage of spent fuel, and COVRA (Central Organization of Radioactive Waste) is the recognized collecting service for this activity. The review was carried out following the requirements set out in IAEA Safety Standards Series No. GSR-Part 5 on the Predisposal Management of Radioactive Waste and should be of considerable interest to the many countries contemplating national waste management and spent fuel policies, implementing strategies and evaluation of their safety.

Radiation Protection and NORM Residue Management in the Titanium Dioxide and Related Industries
Safety Reports Series No. 76
This Safety Report is a compilation of detailed information on the processes and materials involved in the titanium dioxide and related industries and on the radiological considerations that need to be taken into account by the regulatory body when determining the nature and extent of radiation protection measures. It has been developed as part of the IAEA's programme on the application of its safety standards in the field of radiation, transport and waste safety. The information provided will assist in the implementation of a graded approach to regulation, in terms of which the application of the requirements of the safety standards is commensurate with the characteristics of the practice or source and with the magnitude and likelihood of the exposures. Although aimed primarily at the titanium dioxide industry, this publication is also relevant to industries involved in the mining and beneficiation of mineral sands for the extraction of heavy minerals such as zircon, monazite and ilmenite.

(59 pp., 11 figs; 2012) • ISBN 978-92-0-121210-8 • STI/PUB/1533 • €30.00

Safety Assessment for Decommissioning
Safety Reports Series No. 77
The international project on evaluation and demonstration of safety during decommissioning of facilities using radioactive material (DeSa), launched by the IAEA in 2004, helps to ensure that specific guidance on the safety assessment in the context of the decommissioning of nuclear facilities is provided. This publication presents the outcomes of the work carried out in fulfilling the action plan through the DeSa Project. The main features of the process have been summarized and overall recommendations on producing, reviewing and implementing the safety assessment have been made. They are supported by specific recommendations contained in Annexes I–III.

(Forthcoming 2013) • ISBN 978-92-0-141410-6 • STI/PUB/1604 • €44.00

Storage of Spent Nuclear Fuel
Specific Safety Guide
IAEA Safety Standards Series No. SSG-15
This Safety Guide provides guidance and on the storage of spent fuel from nuclear power plants and research reactors. It takes into consideration the longer storage periods that have become necessary owing to delays in the development of disposal facilities and the decrease in reprocessing activities. It also considers developments associated with nuclear fuel, such as higher enrichment, mixed oxide fuels and higher burnup. The Safety Guide is not intended to cover the storage of spent fuel if this is part of the operation of a nuclear power plant or spent fuel reprocessing facility. Guidance is provided on all stages in the lifetime of a spent fuel storage facility, from planning through siting and design to operation and decommissioning, and in particular retrieval of spent fuel.


(110 pp.; 2012) • ISBN 978-92-0-115110-0 • STI/PUB/1503 • €40.00

The Safety Case and Safety Assessment for the Disposal of Radioactive Waste
Specific Safety Guide
IAEA Safety Standards Series No. SSG-23
This Safety Guide provides guidance and recommendations on meeting the safety requirements in respect of the safety case and supporting safety assessment for the disposal of radioactive waste. The safety case and supporting safety assessment provide the basis for demonstration of safety and for licensing of radioactive waste disposal facilities, and assist and guide decisions on siting, design and operations. The safety case is also the main basis on which dialogue with interested parties is conducted and on which confidence in the safety of the disposal facility is developed. This Safety Guide is relevant for operating organizations preparing the safety case as well as for the regulatory body responsible for developing the regulations and
regulatory guidance that determine the basis and scope of the safety case.


(120 pp., 5 figs; 2012) • ISBN 978-92-0-128310-8 • STI/PUB/1553 • €39.00

The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste

General Safety Guide
IAEA Safety Standards Series No. GSG-3

This Safety Guide provides recommendations and guidance for the development and regulatory review of the safety case and supporting safety assessment throughout the lifetime of a facility. The recommendations and guidance provided in this Safety Guide can be used irrespective of how the safety case and safety assessment processes are addressed within national regulatory frameworks. It summarizes the most important considerations in assessing and demonstrating the safety of facilities and activities and recommends the steps that should be followed in developing the safety case and performing the safety assessment.

(151 pp., 10 figs; 2013) • ISBN 978-92-0-134810-4 • STI/PUB/1576 • €37.00

SAFETY ANALYSIS


IAEA TECDOC Series No. 1678

This publication provides a detailed overview of the results and achievements of the IAEA programme called EMRAS (Environmental Modelling for Radiation Safety), which ran from 2003 to 2007. The activities of the various working groups focused on the compilation of a handbook of parameter values for the prediction of radionuclide transfer in temperate environments, on the test and comparison of models to assess the transfer of tritium and 14C to biota and humans, on the validation of models for dose reconstruction due to 131I after the Chernobyl accident, on modelling the transfer of radionuclides in aquatic systems, on remediation of rural and urban sites with radioactive residues, and on the impact of environmental radioactivity on non-human species. The book concludes with a summary of the outcomes of the EMRAS programme and is accompanied by a CD-ROM which provides details of the work and the results of the working groups.


LEGAL AND GOVERNMENTAL ASPECTS

Legal Framework for IAEA Safeguards

The legal framework for IAEA safeguards has evolved significantly since the Board of Governors first approved ad hoc safeguards arrangements in 1959. It is multifaceted, and consists of a number of elements, including: the Statute of the Agency; the undertakings of States in connection with supply arrangements and other treaties requiring verification; the basic safeguards documents; the safeguards instruments themselves, including safeguards agreements, protocols and subsidiary arrangements; and, finally, the decisions and practices of the Board of Governors. This publication provides a succinct, yet comprehensive, review of the current legal framework and its historical development. It introduces IAEA safeguards to the reader and describes the legal framework for their implementation.

(Forthcoming 2013) • ISBN 978-92-0-141810-4 • STI/PUB/1608 • €16.00

Use of External Experts by the Regulatory Body

General Safety Guide
IAEA Safety Standards Series No. GSG-4

This Safety Guide provides recommendations and guidance on meeting the requirements of IAEA Safety Standards Series No. GSR Part 1 on obtaining expert advice or services for the regulatory body. It informs the regulatory body on the process it should use to determine the need for external expert advice, and the processes and procedures for identifying a suitable support provider and making contractual arrangements for the work. It also provides recommendations and guidance on how the regulatory body should take the advice of external experts into account while still retaining responsibility in making its decisions.

(25 pp., 2 figs; 2013) • ISBN 978-92-0-135910-0 • STI/PUB/1583 • €25.00
Benchmark Analyses on the Natural Circulation Test Performed during the PHENIX End-of-life Experiments

IAEA TECDOC Series No. 1703

This publication is based on the experience of an IAEA coordinated research project on control rod withdrawal and sodium natural circulation tests performed during the Phenix end-of-life experiments. Presented in this publication are the benchmark analyses of the natural circulation test performed before the definite shutdown of the reactor. The experimental data gathered during these tests represent a unique resource to carry out validation analyses and code-to-code comparisons. The benchmark analyses allowed participants to investigate and verify several system and safety codes currently used in the analyses of liquid metal thermal hydraulics phenomena in sodium fast reactors.

(Forthcoming 2013) • ISBN 978-92-0-139610-5 • IAEA-TECDOC-1703 • €18.00

Assessing Dynamic Nuclear Energy Systems for Sustainability


IAEA Nuclear Energy Series No. NP-T-1.14

As an integral part of the international project on innovative nuclear reactors and fuel cycles (INPRO), several collaborative projects were established by its members. The collaborative project on global architectures of innovative nuclear energy systems based on thermal and fast reactors including a closed fuel cycle was one of them. This publication presents the study, its results and the conclusions drawn. A major achievement of the project is the development of a unique heterogeneous world model considering specific nuclear energy strategies of various countries. This model simulates important realities of the global nuclear energy system thus enabling the assessment of resource, financial, and proliferation risks and identification of areas for beneficial multilateral cooperation. It shows that innovative nuclear technologies serve as a driving force for enhancing the sustainability features of nuclear energy supply, while a multilateral approach amplifies the positive effects of the technological innovations.

(Forthcoming 2013) • ISBN 978-92-0-140410-7 • STI/PUB/1598 • €40.00

Hydrogen Production Using Nuclear Energy

IAEA Nuclear Energy Series No. NP-T-4.2

A future energy economy will be strongly dependent on the necessity of replacing oil and reducing greenhouse gas emissions for climate protection. Hydrogen has the potential to play an important role as a sustainable and environmentally acceptable source of energy in the 21st century. Yet, there are technical challenges in nuclear hydrogen processes, which need to be addressed through a comprehensive research and development effort. This publication presents the state of the art in the nuclear production of hydrogen and describes the areas of research to be undertaken for establishing a hydrogen economy regime. It includes highlights of international programme and research efforts on nuclear hydrogen production as well as information on hydrogen uses and infrastructure, and provides an introduction to the economic analysis of hydrogen production.

(Forthcoming 2013) • ISBN 978-92-0-135110-4 • STI/PUB/1577 • €42.00

International Safeguards in Nuclear Facility Design and Construction

IAEA Nuclear Energy Series No. NP-T-2.8

This IAEA publication provides guidance on the inclusion of safeguards considerations in nuclear facility design and construction. This first volume introduces the basic principles of Safeguards by design and discusses the goals, costs and rewards, and places the information into the context of nuclear facility design and construction. Benefits and opportunities for all stakeholders are emphasized. The guidance is aimed at enhancing the understanding of nuclear facility vendors and designers regarding the safeguards obligations of both States and the IAEA, at improving the cooperation between all stakeholders in safeguards implementation, and at minimizing the cost of implementation for all stakeholders.

(22 pp.; 2013) • ISBN 978-92-0-140610-1 • STI/PUB/1600 • €19.00

Nuclear Power Reactors in the World

2012 Edition

Reference Data Series No. 2

This is the 32nd edition of Reference Data Series No. 2, which presents the most recent reactor data available to the IAEA. It contains summarized information as of the end of 2011 on power reactors that are in operation, under construction and shutdown, and performance data on reactors operating in IAEA Member States, as reported to the IAEA. The information is collected through designated national correspondents in the Member States and the data are used to maintain the IAEA’s Power Reactor Information System.

(79 pp., 4 figs; 2012) • ISBN 978-92-0-132310-1 • IAEA-RDS-2/32 • €12.00
Assessment of Nuclear Energy Systems Based on a Closed Nuclear Fuel Cycle with Fast Reactors

IAEA TECDOC Series No. 1639/Rev1

This publication reports the results of an evaluation of nuclear energy systems based on a closed nuclear fuel cycle with fast reactors (CNFC-FR). The study was carried out by an international group of experts from Canada, China, France, India, Japan, the Republic of Korea, the Russian Federation and Ukraine, using an assessment methodology developed by the international project on innovative nuclear reactors and fuel cycles (INPRO). The INPRO methodology takes a holistic approach to assess innovative nuclear energy systems in seven areas: economics, infrastructure, safety, waste management, environment, proliferation resistance and physical protection. The study concluded that all INPRO requirements for a sustainable nuclear energy system are fulfilled by the assessed CNFC-FR, except in the area of economics, where ongoing R&D programmes will provide further insights to bridge knowledge gaps. The full text of the study results is available on the accompanying CD-ROM.


Cost Estimation for Research Reactor Decommissioning

IAEA Nuclear Energy Series No. NW-T-2.4

The main aim of this publication is to disseminate experience in and guidance on cost estimates for research reactor decommissioning projects. It presents the principles and background for a costing methodology based on the International Structure for Decommissioning Costing (ISDC) of Nuclear Installations. The methodology presented implements actual experience in decommissioning costing and is in line with IAEA efforts promoting harmonization in this field. The IAEA has contributed to the development of software called CERREX (Cost Estimate for Research Reactors in Excel), a simpler version suitable for preliminary costing stages, which is included on the attached CD-ROM, together with a user manual. Several practical examples of software implementation and clarification of some details of available methodologies and models are also provided.

(Forthcoming 2013) • ISBN 978-92-0-134710-7 • IAEA-TECDOC-1639/Rev1 • €18.00

Electric Grid Reliability and Interface with Nuclear Power Plants

IAEA Nuclear Energy Series No. NG-T-3.8

This publication describes the characteristics of the electrical grid system that are required for the connection and successful operation of a nuclear power plant, as well as the characteristics of a nuclear power plant that are significant for the design and operation of the electrical grid system. It addresses the issues to be considered when a nuclear power plant is being planned and describes the information exchange necessary between the developer of a nuclear power plant and the organization responsible for the electrical grid. The particular issue of a large nuclear unit connected to a small system is also discussed. A new topic introduced in this publication is the need for cyber security of the grid system near the nuclear power plant. Several case studies of Member State experiences in developing new nuclear units and about grid events during operation are included.

(78 pp., 13 figs; 2012) • ISBN 978-92-0-126110-6 • STI/PUB/1542 • €22.00

Invitation and Evaluation of Bids for Nuclear Power Plants

IAEA Nuclear Energy Series No. NG-T-3.9

This publication emphasizes the integrity and interdependence of various activities related to the bid invitation, technical and economic evaluation and contracting. It updates information included in existing IAEA publications in order to better reflect the developments in the nuclear and energy industry, and compiles a more compact and user friendly guidebook integrating the existing IAEA publications on the subject. It provides the information necessary to organize, guide and realize the activities related to the invitation, the technical and economic evaluation of bids, and contracting as an integrated process. Furthermore, this publication indicates how and to what degree the activities preceding the preparation of the bid invitation specification, the evaluation of bids and contracting can influence the process.

(78 pp., 8 figs; 2011) • ISBN 978-92-0-116710-1 • STI/PUB/1536 • €24.00

Managing Siting Activities for Nuclear Power Plants

IAEA Nuclear Energy Series No. NG-T-3.7

This publication has been developed to help Member States ensure that appropriate sites for a nuclear power plant are identified, assessed and licensed, in a well planned and efficient manner, taking into account all relevant factors and lessons learned from recent events. It is applicable to countries with existing nuclear facilities as well as those introducing nuclear power in their energy mix. This
IAEA Nuclear Energy Series publication provides guidance on the complex organizational, engineering, socioeconomic and environmental issues of siting. It complements the IAEA Safety Guides related to site selection and integrates existing IAEA documentation on the subject into a more compact and user-friendly guidebook.

Project Management in Nuclear Power Plant Construction: Guidelines and Experience
IAEA Nuclear Energy Series No. NP-T-2.7
Project management is a leadership function primarily concerned with the organization, coordination and control of large undertakings, with the aim of achieving technical excellence by working to quality standards, optimizing the schedule and the supply chain, and minimizing costs. Competent project management can reduce costs through more efficient work sequences, higher productivity, shorter activity durations and the parallel reduction of accumulated interest during construction of nuclear power plants. Based on past proven practices in Member States, this publication provides guidance on project management from the preparatory phase to plant turnover to commissioning of nuclear power plants. The guidelines and experiences described will enable project managers to obtain better performance in nuclear power plant construction.

Specific Considerations and Milestones for a Research Reactor Project
IAEA Nuclear Energy Series No. NP-T-5.1
A research reactor is an extraordinary tool that can contribute to a country’s scientific resources, improve health care, and help to increase industrial and agricultural productivity, if it is appropriately conceived, managed and supported. This requires a strong policy and technical infrastructure, and management of long term financial liabilities. This publication sets out the four phases of a research reactor project with their associated milestones, starting with a careful assessment of the need for the research reactor, the issues it raises and the measures to address them. The publication provides a framework for self-assessment of readiness for a research reactor project and the resource requirements that it will impose. The guidance provided in this publication will be helpful for decision makers from governments, operating organizations and regulatory bodies as well as project sponsors and planners.

Nuclear Power Operations
Advances in Nuclear Power Process Heat Applications
IAEA TECDOC Series No. 1682
This publication compiles the findings of research and development activities related to practical nuclear process heat applications. An overview of current progress on high temperature gas cooled reactors coupling schemes for different process heat applications, such as hydrogen production and desalination, is included. The associated safety aspects are also highlighted. The summary report documents the results and conclusions of an IAEA coordinated research project.

Operating Experience with Nuclear Power Stations in Member States in 2011
2012 Edition
Operating Experience
This CD-ROM contains the 43rd edition of the IAEA’s series of annual reports on operating experience with nuclear power plants in Member States. It is a direct output from the IAEA’s Power Reactor Information System (PRIS) and contains information on electricity production and overall performance of individual operational plants during 2011. In addition to annual information, the report contains a summary of historical performance during the lifetime of individual plants and figures illustrating worldwide performance of the nuclear industry. The CD-ROM contains also an overview of design characteristics and dashboards of all operating nuclear power plants worldwide.

Reactor Technology
Advanced Surveillance, Diagnostic and Prognostic Techniques in Monitoring Structures, Systems, and Components in Nuclear Power Plants
IAEA Nuclear Energy Series No. NP-T-3.14
This publication reports on the work and findings of an IAEA coordinated research project. The technologies discussed in this project are intended to establish the state of the art in surveillance, diagnostic and prognostic (SDP) technologies for equipment and process health monitoring in nuclear facilities. The participants also identified technology gaps and research needs of the nuclear industry in the SDP area. The publication describes conventional SDP technologies as well as the latest tools, algorithms and techniques that have emerged over the past few years. These new tools have made it possible to identify problems earlier and with better resolution. The target audience of this publication is utility engineers, end users, researchers, managers and executives making decisions on implementation of the subject technologies in nuclear facilities,
or determining the future direction of research and development in this area.

(Forthcoming 2013) • ISBN 978-92-0-140510-4 • STI/PUB/1599 • €30.00

**Advances in High Temperature Gas Cooled Reactor Fuel Technology**

IAEA TECDOC Series No. 1674

This publication reports on the results of a coordinated research project on advances in high temperature gas cooled reactor (HTGR) fuel technology and describes the findings of research activities on coated particle developments. These comprise two specific benchmark exercises with the application of HTGR fuel performance and fission product release codes, which helped compare the quality and validity of the computer models against experimental data. The project participants also examined techniques for fuel characterization and advanced quality assessment/quality control. The key exercise included a round-robin experimental study on the measurements of fuel kernel and particle coating properties of recent Korean, South African and US coated particle productions, applying the respective qualification measures of each participating Member State. The summary report documents the results and conclusions achieved by the project and underlines the added value to contemporary knowledge on HTGR fuel.


**Challenges Related to the Use of Liquid Metal and Molten Salt Coolants in Advanced Reactors**

IAEA TECDOC Series No. 1696

This publication documents the results of experimental investigations and computational fluid dynamics studies on thermal hydraulics, specifically models and correlations on pressure drop and heat transfer involving to liquid metal and molten salt coolants under different operating conditions, including the feedback on neutronics effects. It presents new or verifies existing data on thermo-physical properties of liquid metal and molten salt coolants, and describes tools for on-line monitoring and control of coolant chemistry. Methods to improve the corrosion resistance between heavy liquid metal coolant and components, structure material and instrumentation are also examined.

(Forthcoming 2013) • ISBN 978-92-0-139910-6 • IAEA-TECDOC-1696 • €18.00

**Comparison of Heavy Water Reactor Thermalhydraulic Code Predictions with Small Break LOCA Experimental Data**

IAEA TECDOC Series No. 1688

This publication reports on the second international collaborative intercomparison and validation of computer codes for heavy water reactor (HWR) thermalhydraulic safety analyses. The participants aimed to improve the understanding of important phenomena expected to occur in small break loss of coolant accident transients of HWRs; to evaluate code capabilities to predict these important phenomena, their practicality and efficiency, by simulating integrated experiments; and to suggest necessary code improvements or new experiments to reduce uncertainties. The summary report provides a comparison of the results obtained from six participating countries, utilizing four different computer codes. Lessons learned were summarized, and general conclusions and recommendations were made.


**Design Features and Operating Experiences of Experimental Fast Reactors**

IAEA Nuclear Energy Series No. NP-T-1.9

Growing energy needs and concern for the environment drive the demand for large scale and low impact energy sources. Therefore, national and international research on fast reactor technology is increasing. As a part of the IAEA efforts for knowledge preservation and data retrieval, this publication compiles and documents significant aspects of fast reactor engineering development and experience. Its focus is on research and developing activities, experience with experimental facilities and properties, and criteria for comparison and choice of liquid metal coolants. The introductory part includes the history, the state of the art and an overview of fast reactor cooling, heat transport and heat conversion systems development. This is followed by basic information on liquid metal coolants and design features. The publication concludes with a summary which identifies the progress achieved and issues to be resolved in sodium and heavy metal coolant technology.

(Forthcoming 2013) • ISBN 978-92-0-136410-4 • STI/PUB/1565 • €23.00

**Efficient Water Management in Water Cooled Reactors**

IAEA Nuclear Energy Series No. NP-T-2.6

In an effort to illustrate the sustainability of nuclear power, this publication discusses current practices for water requirements in nuclear power plants, possible future trends in design of water cooled reactors and the technologies employed. It analyses best practices and strategies for lower water withdrawal rates and presents the trade-off between production of electricity and water use and consumption, explaining types of cooling systems to be selected. The book thus aims at enhancing the understanding of the issues related to water use, consumption and management in a larger picture.

(116 pp., 76 figs; 2012) • ISBN 978-92-0-132610-2 • STI/PUB/1569 • €34.00

**Fast Reactors and Related Fuel Cycles: Challenges and Opportunities (FR09)**

Proceedings of an International Conference held in Kyoto, Japan, 7–11 December 2009

This is the proceedings of an international conference on fast reactors and related fuel cycles convened to exchange experience and innovative ideas in order to achieve
progress in this field. Fast reactor programmes are currently on an accelerated growth path in many countries of the world, and the last international fast reactor conference was held almost twenty years ago. The scope of discussion included key scientific and technological areas, such as fuels and materials development, safety, advanced simulation, component and system design, and coolant technology, in which innovation is pursued to ensure that the next generations of fast reactor fuel cycles will achieve their potential. The accompanying CD-ROM contains the contributed papers and posters, summaries of 150 oral presentations and the young generation event.

Liquid Metal Coolants for Fast Reactors (Reactors Cooled by Sodium, Lead and Lead-bismuth Eutectic)
IAEA Nuclear Energy Series No. NP-T-1.6
The choice of the coolant is one of the main technical issues concerning fast reactor design, since it determines design approach as well as safety, technical and economic characteristics of the system. This publication provides a comprehensive summary of the status of the liquid metal coolant technology development for fast reactors with regard to basic data and main technological challenges. It starts with remarks on the history of nuclear power development, provides a complete survey of physical and chemical properties of liquid metals, and discusses the coolant quality control and thermal-hydraulics studies for both sodium and lead alloys systems. Other chapters elaborate on radioactivity of coolants and describe past experiences as well as current projects. Finally, the design objectives, and main research and technology development challenges of innovative fast reactors having sodium, lead-bismuth eutectic, and lead as coolant, currently under investigation in the Russian Federation, as well as the status of the respective research and development activities, are summarized.

Modelling of Transport of Radioactive Substances in the Primary Circuit of Water Cooled Reactors
IAEA TECDOC Series No. 1672
The formation, release and deposition of corrosion products within the primary circuit of a nuclear power plant can lead to fuel damage, power distortions during operation and radiation fields that affect plant maintenance. This publication provides information on the modelling of corrosion product behaviour in the primary circuit. It reports on the research activities and results from an IAEA coordinated research project in this field and includes details of current best practice. These data are important elements for the current understanding of the formation and transport mechanisms of corrosion products involved in both light water reactors and pressurized water reactors, and the methods used to describe them.

Natural Circulation Phenomena and Modelling for Advanced Water Cooled Reactors
IAEA TECDOC Series No. 1677
Based on an IAEA coordinated research project focused on the use of passive safety systems and natural circulation to help meet the safety and economic goals of advanced nuclear power plants, this publication includes: the identification and definition of the thermo-hydraulic phenomena that affect the reliability of passive safety systems; characterization of each phenomenon; integral tests to examine the passive systems and natural circulation; and a methodology for examining passive system reliability.

Nuclear Reactor Technology Assessment for Near Term Deployment
IAEA Nuclear Energy Series No. NP-T-1.10
Given the increasing interest in the near term deployment of new nuclear power plants, IAEA Member States have requested guidance on the process of evaluating and selecting available technology options. Reactor technology assessment enables the evaluation, selection, and deployment of the best technology to meet the objectives of a nuclear power programme. This publication demonstrates how reactor technology assessment is performed and how the process and results of this work enable decision makers in nuclear power planning. The approach also provides decision makers with the documentation necessary to support their conclusions.

Performance Assessment of Passive Gaseous Provisions (PGAP)
IAEA TECDOC Series No. 1698
The international project on innovative nuclear reactors and fuel cycle (INPRO) initiated a collaborative project to contribute to an international consensus on the definition of the reliability of passive systems that involves natural circulation, and a methodology to assess this reliability. Different reliability methodologies available in Member States were used to assess the performance and reliability of passive decay heat removal system of the French gas cooled fast reactor (GFR) design for various transients. This publication is the final report of this project and summarizes the results of the participants’ work concerning the evaluation of the performance and reliability of the passive decay heat removal system of the GFR design. The report also presents a unified definition of the reliability of thermal hydraulic passive system, and the possibility of unifying the features of the methodologies in order to develop a generic methodology.
**Status of Fast Reactor Research and Technology Development**

**IAEA TECDOC Series No. 1691**

Based on a recommendation from the Technical Working Group on Fast Reactors, this publication is a regular update of previous publications on fast reactor technology. The publication provides comprehensive and detailed information on the technology of fast neutron reactors. The focus is on practical issues that are useful to engineers, scientists, managers, university students and professors. The main issues discussed are experience in design, construction, operation and decommissioning, various areas of research and development, engineering, safety and national strategies, and public acceptance of fast reactors. The summary includes national strategies, international initiatives on innovative (i.e. Generation IV) systems and an assessment of public acceptance of fast reactors.

(2013) • ISBN 978-92-0-130610-4 • IAEA-TECDOC-1691 • €35.00

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**Quality Assurance**

**Assessing and Managing Cable Ageing in Nuclear Power Plants**

**IAEA Nuclear Energy Series No. NP-T-3.6**

Cable ageing and the need for condition monitoring are the most important aspects of plant life extension when it comes to instrumentation and control systems. Cables, especially their insulation and jacket material, are vulnerable to ageing degradation during normal operation, and means must be established to ensure that cable ageing does not lead to unsafe operation. This publication addresses all relevant issues related to cable ageing and contains introductory level materials that present a summary of key issues in cable ageing in nuclear power plants. In particular, it provides guidelines for cable qualification and cable ageing management in nuclear facilities, reflecting the technical advances of the past 15 years.

(96 pp., 42 figs; 2012) • ISBN 978-92-0-128510-2 • STI/PUB/1554 • €30.00

**Evaluation of High Temperature Gas Cooled Reactor Performance: Benchmark Analysis Related to the PBMR-400, PBMM, GT-MHR, HTR-10 and the ASTRA Critical Facility**

**IAEA TECDOC Series No. 1694**

This publication presents the findings of an IAEA coordinated research project (CRP) focusing on validation of the safety and operational aspects of high temperature gas cooled reactors (HTGRs) under projected and actual operating conditions. Specifically, it documents the results of a benchmark analysis of the ASTRA critical facility at the Kurchatov Institute in the Russian Federation, with respect to the development of pebble-bed high temperature modular reactor (PBMR-400). It also presents results of benchmark analyses performed for the HTR-10 experimental reactor in China, and the pebble-bed micro model test facility in South Africa. Such benchmarks include core height prediction for criticality, control rod worth and related differential reactivity and interference coefficients, and investigation of critical parameters for differing heights of the pebble-bed high temperature modular reactor. Code-to-code comparison as well as comparison with actual experimental data make the information obtained from this CRP valuable for verification and validation of HTGR design and analysis codes for future developers of HTGR power plants. General results and conclusions as delineated by the participating Member States are described in the summary.

(Forthcoming 2013) • ISBN 978-92-0-137610-7 • IAEA-TECDOC-1694 • €32.00

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**Human Resource Development for Introducing and Expanding Nuclear Power Programmes**

**Summary of an International Conference held in Abu Dhabi, United Arab Emirates, 14–18 March 2010**

**Proceedings Series**

This publication is the proceedings of an international conference on human resource development for introducing and expanding nuclear power programmes. Experts from many Member States discussed the current state of human resource development in the nuclear field and addressed concerns about possible shortages of qualified people. The conference identified several issues for consideration by national governments, international organizations, industry and stakeholders and highlighted the importance of sharing knowledge and expertise. One of the main goals of the conference was to provide participants with practical tools that can be used at the organizational, national and international levels to develop and maintain the human resources needed to support the safe and sustainable introduction and expansion of nuclear power programmes. These proceedings include a summary, the opening and closing speeches and invited papers. The publication also includes a CD-ROM which contains the contributed papers and presentations.

(54 pp., 2 figs; 2012) • ISBN 978-92-0-134410-6 • STI/PUB/1574 • €40.00

**Knowledge Management for Nuclear Research and Development Organizations**

**IAEA TECDOC Series No. 1675**

This publication elaborates on the role of nuclear knowledge management in a research and development (R&D) context, and on the importance of facilitating innovation and future development of nuclear technologies for nuclear power, its associated fuel cycles, and nuclear applications in medicine, industry and agriculture. It highlights aspects such as transferring and preserving knowledge, establishing and supporting cooperative networks, and training the next generation of nuclear experts. It concludes with basic concepts, trends and key drivers for nuclear knowledge management.
Managing Organizational Change in Nuclear Organizations
IAEA Nuclear Energy Series No. NG-T-1.1

It is widely recognized that engineering changes, if not properly considered and controlled, can have potentially major safety implications; however, organizational changes can also have potentially major safety implications. This publication is intended to assist the management of nuclear organizations in identifying, planning and implementing organizational change. The driving force for the change may be internal or external. Based on the assumption that any change made within a facility applying nuclear technology has the potential to impact safety and effectiveness. The publication provides a description of the basic principles for managing and implementing the organizational change effectively while remaining focused on safe and reliable operation. The guidance contained in the publication is relevant to all organizational changes within nuclear organizations.

(Forthcoming 2013) • ISBN 978-92-0-140910-2 • STI/PUB/1603 • €36.00

Risk Management of Knowledge Loss in Nuclear Industry Organizations

Maintaining nuclear competencies in the nuclear industry and in nuclear regulatory bodies will be one of the most critical challenges in the near future. As nuclear experts around the world retire, they are taking with them a substantial amount of knowledge and corporate memory. The loss of such employees, who hold knowledge critical to both operations and safety, poses a clear internal threat to the safe and reliable operation of nuclear facilities. This publication is intended for senior and middle level managers of nuclear industry operating organizations and provides practical information on knowledge loss risk management. The information provided in this publication is based on actual experiences of Member State operating organizations and is intended to increase awareness of the need to develop a strategic approach and action plans to address the potential loss of critical knowledge and skills; to provide processes and, in conducting risk assessments, to determine the potential for loss of critical knowledge caused by the loss of experienced workers; and to enable nuclear organizations to utilize this knowledge to improve the skill and competence of new and existing workers.

English Edition (31 pp., 1 fig.; 2006) • ISBN 92-0-105406-8 • STI/PUB/1248 • €18.00
Russian Edition (36 pp., 1 fig.; 2012) • ISBN 978-92-0-432210-1 • STI/PUB/1248 • €18.00
Assessment of Nuclear Energy Systems Based on a Closed Nuclear Fuel Cycle with Fast Reactors
IAEA TECDOC Series No. 1639/Rev1

This publication reports the results of an evaluation of nuclear energy systems based on a closed nuclear fuel cycle with fast reactors (CNFC-FR). The study was carried out by an international group of experts from Canada, China, France, India, Japan, the Republic of Korea, the Russian Federation and Ukraine, using an assessment methodology developed by the international project on innovative nuclear reactors and fuel cycles (INPRO). The INPRO methodology takes a holistic approach to assess innovative nuclear energy systems in seven areas: economics, infrastructure, safety, waste management, environment, proliferation resistance and physical protection. The study concluded that all INPRO requirements for a sustainable nuclear energy system are fulfilled by the assessed CNFC-FR, except in the area of economics, where ongoing R&D programmes will provide further insights to bridge knowledge gaps. The full text of the study results is available on the accompanying CD.


Fast Reactors and Related Fuel Cycles: Challenges and Opportunities (FR09)
Proceedings of an International Conference held in Kyoto, Japan, 7–11 December 2009
Proceedings Series

This is the proceedings of an international conference on fast reactors and related fuel cycles convened to exchange experience and innovative ideas in order to achieve progress in this field. Fast reactor programmes are currently on an accelerated growth path in many countries of the world, and the last international fast reactor conference was held almost twenty years ago. The scope of discussion included key scientific and technological areas, such as fuels and materials development, safety, advanced simulation, component and system design, and coolant technology, in which innovation is pursued to ensure that the next generations of fast reactor fuel cycles will achieve their potential. The accompanying CD-ROM contains the contributed papers and posters, summaries of 150 oral presentations and the young generation event.

(393 pp., 85 figs; 2012) • ISBN 978-92-0-102410-7 • STI/PUB/1444 • €98.00

Overcoming Barriers in the Implementation of Environmental Remediation Projects
IAEA Nuclear Energy Series No. NW-T-3.4

Environmental remediation has been in existence for decades, and a tremendous body of practical and scientific knowledge has been developed in many areas. Responding to the needs of Member States, the IAEA has initiated an environmental remediation project to address radioactive contamination found in soils and waters. This publication discusses the drivers on environmental remediation as well as the major obstacles confronted by any remediation operation and how to overcome those obstacles. It includes a number of potential strategies that may provide effective remediation outcomes and that have been deemed to be cost effective by Member States. Implementers of an environmental remediation programme as well as regulators will benefit from the information and guidance provided in this publication.

(Forthcoming 2013) • ISBN 978-92-0-140810-5 • STI/PUB/1602 • €24.00
Planning, Management and Organizational Aspects in Decommissioning of Nuclear Facilities

IAEA TECDOC Series No. 1702

This publication reflects the results of an IAEA coordinated research project on non-technical aspects of decommissioning. Operating experience and lessons learned during full-scale applications, as well as national programmes and plans, are among the most significant achievements. The results help to improve understanding of specific characteristics of the decommissioning process that are important in the planning and implementation of decommissioning. The information provided will be particularly useful to Member States that are currently planning or implementing decommissioning of their nuclear facilities.

(Forthcoming 2013) • ISBN 978-92-0-139510-8 • IAEA-TECDOC-1702 • €18.00

Policies and Strategies for the Decommissioning of Nuclear and Radiological Facilities

IAEA Nuclear Energy Series No. NW-G-2.1

This publication presents the main elements of policies and strategies for decommissioning activities of nuclear and radiological facilities. It is intended to help in facilitating proper and systematic planning, and safe, timely and cost effective implementation of all decommissioning activities. The policy establishes the principles for decommissioning, and the strategy contains the approaches for implementation of the policy. The publication will be a useful guide for strategic planners, waste managers, operators of facilities under decommissioning, regulators and other stakeholders.

(30 pp.; 2012) • ISBN 978-92-0-116910-5 • STI/PUB/1525 • €24.00

Safety Assessment for Decommissioning

Safety Reports Series No. 77

The international project on evaluation and demonstration of safety during decommissioning of facilities using radioactive material (DeSa), launched by the IAEA in 2004, helps to ensure that specific guidance on the safety assessment in the context of the decommissioning of nuclear facilities is provided. This publication presents the outcomes of the work carried out in fulfilling the action plan through the DeSa Project. The main features of the process have been summarized and overall recommendations on producing, reviewing and implementing the safety assessment have been made. They are supported by specific recommendations contained in Annexes I–III.

(Forthcoming 2013) • ISBN 978-92-0-141410-6 • STI/PUB/1604 • €44.00

Water Chemistry and Clad Corrosion/Deposition Including Fuel Failures

Proceedings of a Technical Meeting held in Kiev, Ukraine, 22–24 November 2010

IAEA TECDOC CD Series No. 1692

This publication presents the proceedings of a technical meeting on water chemistry and cladding corrosion/deposition including fuel failures, which was held in Kiev, Ukraine, in 2010. The outcome of the meeting is a summary report which provides state of the art information on the corrosion of reactor material, including fuel cladding, the causes of corrosion product deposition and the means in use to minimize the deleterious effects of these processes. The meeting was attended by 22 participants from 15 countries; papers were presented in three technical sessions, covering operational experience, corrosion and oxidation, and cladding deposition and its consequences.


Fuel Fabrication and Performance

Advances in High Temperature Gas Cooled Reactor Fuel Technology

IAEA TECDOC Series No. 1674

This publication reports on the results of a coordinated research project on advances in high temperature gas cooled reactor (HTGR) fuel technology and describes the findings of research activities on coated particle developments. These comprise two specific benchmark exercises with the application of HTGR fuel performance and fission product release codes, which helps compare the quality and validity of the computer models against experimental data. The project participants also examined techniques for fuel characterization and advanced quality qualification measures of each participating Member State. The summary report documents the results and conclusions achieved by the project and underlines the added value to contemporary knowledge on HTGR fuel.


BN-600 MOX Core Benchmark Analysis: Results from Phases 4 and 6 of a Coordinated Research Project on Updated Codes and Methods to Reduce the Calculation Uncertainties of the LMFR Reactivity Effects

IAEA TECDOC Series No. 1700

This publication presents the main results and achievements of an undertaking (part of a wider IAEA coordinated research project) devoted to the benchmark analyses of two mixed-oxide (MOX) fuelled BN-600 core designs. The studies conducted contributed to the progress in development, verification and validation of new codes and data libraries for fast reactor analyses; promoted deeper understanding of the influence of reactivity coefficients and their uncertainties on the results.
of experience and transient analyses in the initial phase of transients, such as unprotected loss of flow (ULOF); and facilitated exchange of opinions between specialists.

(Forthcoming 2013) • ISBN 978-92-0-139210-7 • IAEA-TECDOC-1700 • €18.00

Design, Manufacturing and Irradiation Behaviour of Fast Reactor Fuel
IAEA TECDOC Series No. 1689
This publication presents the proceedings of a technical meeting organized in order to share knowledge and practical experience on the improvement and innovation of fuels for fast reactors. The objective of the meeting was to provide an overview of the status of the design, manufacture and irradiation behaviour of fast reactor fuels. Scientists and engineers from different fields discussed critical issues, with the aim of supporting efforts related to the design and manufacture of nuclear fuels for the existing and next generation of fast reactors, as well as the optimization of future irradiation experiments.

(Forthcoming 2013) • ISBN 978-92-0-186510-6 • IAEA-TECDOC-CD-1689 • €18.00

Experiences and Trends of Manufacturing Technology of Advanced Nuclear Fuels
IAEA TECDOC Series No. 1686
This publication is a compilation of updated information on experience and trends in manufacturing technology of nuclear fuels for power reactors, and research reactors and highlights emerging trends. Although the fuel cladding and other structural components of fuel element and fuel assembly are integral parts of the fuel, this publication does not cover the manufacturing of these non-fissile and non-fertile components. It focuses on fabrication processes for matured fuels such as UO₂ and mixed oxide (MOX) for water cooled power reactors and sodium cooled fast reactors (SFRs), emerging SFR fuel such as mixed carbide and nitride, U-Pu-Zr with and without minor actinides (MA) and thorium based fuels for power reactors; and aluminium matrix dispersion type fuels and monolithic fuels for research reactors. The publication is divided into six chapters, describing in detail the features of the fuels and concludes with a summary identifying the gaps in information and the areas of future research and development.


Fuel Modelling at Extended Burnup (FUMEX-II)
IAEA TECDOC Series No. 1687
The modelling of nuclear fuel performance is critical to the safe and economic operation of nuclear power plants. It is necessary to be able to properly understand and predict the behaviour of fuel in both normal and transient conditions. As fuel is taken to higher burnups, it is important to ensure that the tools used to model the behaviour remain appropriate as fuel designs and materials change. This publication presents the results of a code comparison exercise against a wide range of experimental and idealized data designed to test the limits of code capabilities and to allow data for verification and validation at high burnup. It provides an overview of the codes, their limitations and the main challenges in understanding the behaviour of high burnup fuel and how these are met.


Improvement of Computer Codes Used for Fuel Behaviour Simulation (FUMEX -III)
IAEA TECDOC Series No. 1697
The modelling of the performance of nuclear fuel is crucial to the operation of nuclear power plants and comprises a key component of the demonstration of nuclear safety. As the demands on fuel performance increase, fuel modelling codes need to develop and cover a wider range of operational and transient conditions. This publication compares the predictions of current fuel modelling codes with data representing a wide range of fuel operational conditions. The results demonstrate both excellent performance and areas for further development of the codes to support advanced fuel operations.


Role of Thorium to Supplement Fuel Cycles of Future Nuclear Energy Systems
IAEA Nuclear Energy Series No. NF-T-2.4
The investigation of the thorium fuel cycle is a collaborative INPRO (International Project on Innovative Nuclear Reactors and Fuel Cycles) activity within the main area of global vision of sustainable nuclear energy for the 21st century. The current publication reports on the sustainability of nuclear power by re-examining the potential of thorium based fuel cycles to support future large scale deployment of nuclear energy systems by increasing the availability of nuclear material. Special attention is paid to the thorium fuel cycle from the point of view of economics and proliferation resistance.

(157 pp., 103 figs; 2012) • ISBN 978-92-0-125910-3 • STI/PUB/1540 • €36.00
Spent Fuel Performance Assessment and Research: Final Report of a Coordinated Research Project (SPAR-II)

IAEA TECDOC Series No. 1680

Spent fuel storage has become an important component of spent fuel management options. As storage durations increase, spent fuel performance is a critical issue. This publication presents the results of an IAEA coordinated research project on this topic and contains useful information on the integrity and degradation of spent fuel during storage. The experience and insights provided by the participating countries will help Member States to identify challenges in implementing long term storage and to understand the current status of spent fuel performance research related to long term storage.


Structural Materials for Liquid Metal Cooled Fast Reactor Fuel Assemblies — Operational Behaviour

IAEA Nuclear Energy Series No. NF-T-4.3

This publication summarizes the findings of several IAEA meetings on fast reactor materials and provides a review of historically available and new information on the properties, fabrication technologies and irradiation behaviour of stainless steel structural materials for liquid metal cooled fast reactor (LMFR) fuel assemblies. It identifies different varieties of austenitic, ferritic–martensitic, oxide dispersion strengthened (ODS) steels and nickel based alloys used or planned to be used as fuel cladding and structural components of fast reactor fuel assemblies; describes manufacturing processes of LMFR fuel cladding tubes and in-core components; and provides an overview of the operational behaviour of these materials in fast reactors. Particular attention is given to ODS steels as the promising path towards achieving higher fuel burnup in fast reactors.

(87 pp., 70 figs; 2012) • ISBN 978-92-0-127510-3 • STI/PUB/1548 • €31.00

SPENT FUEL MANAGEMENT

Management and Storage of Research Reactor Spent Nuclear Fuel

Proceedings of a Technical Meeting held in Thurso, United Kingdom, 19–22 October 2009

Proceedings Series

The intermediate storage of research reactor spent nuclear fuel is a real challenge for operators, as this period in some cases can extend for over 50 years until a final decision is made. This publication presents the proceedings of a technical meeting to discuss good practices for the management and storage of research reactor spent fuel. The information provided on these issues will be of interest to managers of research reactors and research reactor spent nuclear fuel facilities.

(262 pp., 50 figs; 2013) • ISBN 978-92-0-138210-8 • STI/PUB/1592 • €49.00

WASTE MANAGEMENT

Management of NORM Residues

IAEA TECDOC Series No. 1712

Naturally occurring radioactive material (NORM) may lead to exposures at some stage of its processing and in the use or reuse of products, residues or wastes. Several IAEA publications address NORM issues with a special focus on some of the more relevant industrial operations. This publication addresses the management aspects of NORM residues, including their disposal as waste, in a wide range of industrial activities involving minerals and raw materials. It also addresses NORM residues at so-called legacy sites, that is, sites contaminated by past activities that were not regulated to present standards. The main intention of this publication is to provide guidance to Member States on good practice in the management of NORM residues, bearing in mind that there is no single approach that applies to all situations.

(Forthcoming 2013) • ISBN 978-92-0-142710-6 • IAEA-TECDOC-1712 • €18.00

Mobile Processing Systems for Radioactive Waste Management

IAEA Nuclear Energy Series No. NW-T-1.8

In recent years, mobile systems have increasingly been deployed for the processing of different types of radioactive waste. Such systems offer flexibility in selection and application of the optimum technology for a specific waste stream by bringing the process to the point where the waste is generated, with the additional benefit that there can be equipment sharing among multiple generating sites. This publication provides the basic information on utilization of mobile systems for waste processing and introduces a methodology for the assessment required to determine the viability of mobile systems for specific applications. In addition, it informs the reader on the accurate assessment of mobile systems that employ one or more technologies. The target audience is professionals involved in the planning, selection, design, deployment and regulation of radioactive waste processing facilities.

(Forthcoming 2013) • ISBN 978-92-0-141010-8 • STI/PUB/1621 • €30.00

Options for Management of Spent Fuel and Radioactive Waste for Countries Developing New Nuclear Power Programmes

IAEA Nuclear Energy Series No. NW-T-1.24

Countries embarking upon a nuclear power programme need to understand the importance of establishing an adequate radioactive waste and spent nuclear fuel management infrastructure. To assist in overcoming any challenges this might represent, this publication provides an overview of management practices in use in mature nuclear power programmes. Primarily
addressing decision makers, it provides them with the level of strategic and technical information needed to understand overarching management issues of the various waste streams and spent fuel generated in nuclear power production. In addition, it examines the political, legal, societal, economic and technical challenges associated with each of the strategic options considered.

(Forthcoming 2013) • ISBN 978-92-0-140710-8 • STI/PUB/1601 • €23.00

Radiation Protection and Management of NORM Residues in the Phosphate Industry
Safety Reports Series No. 78

This Safety Report is a compilation of detailed information on the processes and materials associated with the phosphate industry and on the radiological considerations that need to be taken into account by the regulatory body when determining the nature and extent of radiation protection measures. It has been developed as part of the IAEA's programme on the application of its safety standards in the field of radiation, transport and waste safety. The information provided will assist in the implementation of a graded approach to regulation, in terms of which the application of the requirements of the safety standards is commensurate with the characteristics of the practice or source and with the magnitude and likelihood of the exposures. The publication also provides information on expected radionuclide concentrations, exposure levels and the most appropriate regulatory approach in the phosphate industry, and covers the mining and beneficiation of phosphate ore, phosphoric acid production, phosphogypsum, and the manufacture and use of phosphatic fertilizers among others.

(288 pp., 90 figs; 2013) • ISBN 978-92-0-135810-3 • STI/PUB/1582 • €55.00

Remediation of Land Affected by Radioactive Residues
Proceedings Series

This publication presents the proceedings of an international conference on remediation of radioactive contaminated sites with a particular focus on the countries of central Asia. The conference provided a forum for all parties involved in remediation of such sites to gather and exchange ideas, review progress and new developments, compare technologies and methods, and thus disseminate information and experience. The key topical issues identified and discussed by the participants included regulatory and safety regimes, innovative and mature technologies, life cycle planning, technical experience exchange, stakeholder issues, and international cooperation and support. A series of case studies are presented to provide an overview of environmental remediation activities in different parts of the world. The publication summarizes the present status and outlines future trends in environmental remediation technologies and methods, and identifies possible areas for improvement.

(Forthcoming 2013) • ISBN 978-92-0-142310-8 • STI/PUB/1612 • €75.00

Review of Sealed Source Designs and Manufacturing Techniques Affecting Disused Source Management
IAEA TECDOC Series No. 1690

Sealed radioactive sources are widely used in industry, medicine and research, and are often small and mobile. The nuclear community has taken special care of all aspects affecting the management of sealed sources, including disused sources and their individual designs. This publication collects information on the most typical design features and manufacturing techniques of sealed radioactive sources and examines how they affect the management of disused radioactive sources. The approaches and methods described will also be useful for source designers and manufacturers in helping them to consider waste management points of view when they improve their products.


The Behaviour of Cementitious Materials in Long Term Storage and Disposal of Radioactive Waste — Results of a Coordinated Research Project
IAEA TECDOC Series No. 1701

This publication presents the outcome of an IAEA coordinated research project that investigated the behaviour and performance of cementitious materials used for an overall waste conditioning system. The publication is intended to assist the reader in comparing cementitious systems and technologies and in reaching an informed decision based on safety, technological maturity, economics, and other local needs. It highlights the active interchange of experiences among leading research groups, which enabled them to access valuable information on the underlying science and technology of cementitious materials used in radioactive waste management. The publication can be used as a screening tool to identify cementitious systems and technologies to meet specific waste management objectives in terms of the conditioning of waste generated, the technical complexity of waste streams, the environmental impact considerations and the desired end product.

(Forthcoming 2013) • ISBN 978-92-0-139310-4 • IAEA-TECDOC-1701 • €18.00
Trapped tritium. Measurements of tritium inventory and means to remove the tritium. The key topics are the retention of tritium in fusion wall materials, plasma-facing materials. This volume of Atomic and Plasma–Material Interaction Data for Fusion is a result of a coordinated research project (CRP) on tritium inventory in fusion reactors, which brought together specialists in fusion materials and plasma–material interaction for exchange of information and coordination of research activities on interaction of tritium with plasma-facing materials. This volume of Atomic and Plasma–Material Interaction Data for Fusion is a result of that CRP. The key topics are tritium retention in fusion wall materials, measurements of tritium inventory and means to remove trapped tritium.

(90 pp., 101 figs.; 2012) • ISBN 978-92-0-131410-9 • STI/PUB/023/APID/15 • €40.00

Atomic and Plasma–Material Interaction Data for Fusion Vol. 16

Atomic and Plasma–Material Interaction Data for Fusion

This publication, arising from a Coordinated Research Project on Atomic and Molecular Data for Plasma Modelling, provides information on new data relevant to the edge region of plasmas in nuclear fusion energy devices. In this region, molecules and molecular ions are formed and react with electrons and with each other. Fusion plasma modelling requires cross-sections and rate coefficients for such processes. This volume describes new data and data compilations for atomic and molecular processes that occur in edge plasma and provides data in forms that can be used in plasma modelling codes.

(Forthcoming 2013) • ISBN 978-92-0-131510-6 • STI/PUB/023/APID/16 • €40.00

Dense Magnetized Plasmas

IAEA TECDOC Series No. 1699

This publication presents results achieved within an IAEA coordinated research project on dense magnetized plasmas (DMPs) with respect to the needs of plasma research in developed and developing IAEA Member States, performed under comprehensive international collaboration. Of specific interest is the improvement of experimental set-ups for DMPs, including new ideas on drivers, chambers and targets, interface issues and plasma–wall interactions. Better understanding of discharge physics and control, improved theory and numerical modelling using various codes are reported. Important issues are diagnostics development, materials testing and development, and post-irradiation materials diagnostics and analysis. This publication illustrates the speed of progress in DMP applications facilitated by the sharing of knowledge, staffing and costs, and the promotion of technology transfer among Member States. Nuclear energy from inertial fusion is clean, safe and abundant, and therefore has the potential to develop into a viable option in any given energy portfolio. This publication presents the results and achievements of an IAEA coordinated research project on this topic. The project brought together experts from 16 institutions in 14 Member States to address issues relevant to advancing inertial fusion energy research and development towards practical applications. Key issues discussed include beam–plasma matter interactions, drivers options and technology as well as target fabrication technology, and inertial fusion power plant and integration.

International Safeguards in Nuclear Facility Design and Construction
IAEA Nuclear Energy Series No. NP-T-2.8
This IAEA publication provides guidance on the inclusion of safeguards considerations in nuclear facility design and construction. This first volume introduces the basic principles of Safeguards by design and discusses the goals, costs and rewards, and places the information into the context of nuclear facility design and construction. Benefits and opportunities for all stakeholders are emphasized. The guidance is aimed at enhancing the understanding of nuclear facility vendors and designers regarding the safeguards obligations of both States and the IAEA, at improving the cooperation between all stakeholders in safeguards implementation, and at minimizing the cost of implementation for all stakeholders.

(22 pp.; 2013) • ISBN 978-92-0-140610-1 • STI/PUB/1600 • €19.00

Preparing for Future Verification Challenges
Proceedings of an International Safeguards Symposium held in Vienna, 1–5 November 2010
IAEA safeguards symposia are important forums for substantive and detailed interaction between the Secretariat of the IAEA, its Member States and the international community on safeguards and verification issues. The 11th Symposium on International Safeguards, Preparing for Future Verification Challenges, was held in Vienna, Austria, from 1 to 5 November 2010. The aim of the symposium was to help the IAEA to prepare for future verification challenges by engaging in dialogue and information exchange with Member States, technical experts, the nuclear industry and members of the broader safeguards and nuclear non-proliferation community. This publication provides a summary of the symposium plenaries, technical sessions, panels and forums.

(66 pp.; 2013) • ISBN 978-92-0-142110-4 • STI/PUB/1611 • €82.00
Exemption from Regulatory Control of Goods Containing Small Amounts of Radioactive Material
IAEA TECDOC Series No. 1679

This publication examines some of the issues that need to be considered in relation to authorization and exemption from regulatory control, focusing in particular on consumer products and other goods containing small amounts of radioactive material. All aspects of their life cycle following manufacture, including transport, storage, supply use and disposal, are considered. The publication aims to generate discussion on how the concepts of authorization and exemption should be applied with a view to developing an internationally accepted, harmonized approach.


IAEA International Law Series No. 5

This publication complements IAEA International Law Series No. 3 and reproduces the explanatory text on the 1988 Joint Protocol Relating to the Application of the Vienna Convention on Civil Liability for Nuclear Damage and the Paris Convention on Third Party Liability in the Field of Nuclear Energy. Finalized by the International Expert Group on Nuclear Liability (INLEX), this text constitutes a comprehensive study and authoritative interpretation of that instrument.

(37 pp.; 2013) • ISBN 978-92-0-139410-1 • STI/PUB/1593 • €38.00
Guidelines for Remediation Strategies to Reduce the Radiological Consequences of Environmental Contamination
Technical Reports Series No. 475

This publication addresses the remediation of non-urban terrestrial and freshwater ecosystems including agricultural, forest and aquatic environments contaminated with radionuclides by radiation accidents, radiological incidents and other past activities. Associated social, ethical and economic considerations are also presented. The book describes modern decision aiding technologies and environmental decision support systems for remediation planning and optimization. Several case studies, demonstrating remediation success (radiation and radiological accidents, nuclear test sites, etc.) are presented and evaluated. The publication considers only remediation strategies and management options that are relevant for existing exposure situations. Management options (countermeasures) for pre-deposition and early phases after emergencies are the subject of other IAEA publications.

(167 pp., 12 figs; 2013) • ISBN 978-92-0-134110-5 • STI/DOC/010/475 • €46.00

Isotopes in Hydrology, Marine Ecosystems and Climate Change Studies
Proceedings of the International Symposium held in Monaco, 27 March–1 April 2011
Proceedings Series

This publication presents the proceedings of the latest IAEA symposium on isotopes in hydrology, marine ecosystems and climate change studies. At the symposium, five major topics were addressed through invited talks and oral presentations. These five sessions covered: the role of isotopes in understanding and modelling climate change, marine ecosystems and the water cycle; carbon dioxide sequestration and related aspects of the carbon cycle, such as ocean acidification; isotopes and radionuclides in the marine environment; groundwater assessments for large aquifers; analytical methods and instrumentation for the application of isotopes in environmental, climate and hydrological studies. Leading scientists in the field of climate change and hydrology, as well as representatives from climate change and environmental bodies and organizations, exchanged their views and experience.

(Forthcoming 2013) • ISBN 978-92-0-135610-9 • STI/PUB/1580 • €90.00

Overcoming Barriers in the Implementation of Environmental Remediation Projects
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Environmental remediation has been in existence for decades, and a tremendous body of practical and scientific knowledge has been developed in many areas. Responding to the needs of Member States, the IAEA has initiated an environmental remediation project to address radioactive contamination found in soils and waters. This publication discusses the drivers on environmental remediation as well as the major obstacles confronted by any remediation operation and how to overcome those obstacles. It includes a number of potential strategies that may provide effective remediation outcomes and that have been deemed to be cost effective by Member States. Implementers of an environmental remediation programme as well as regulators will benefit from the information and guidance provided in this publication.

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Proceedings Series

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(Forthcoming 2013) • ISBN 978-92-0-142310-8 • STI/PUB/1612 • €75.00
Sources and Measurements of Radon and Radon Progeny Applied to Climate and Air Quality Studies

Proceedings Series

The naturally occurring radionuclide radon ($^{222}$Rn), together with its radioactive progeny, has been widely used to study atmospheric processes and to test and validate comprehensive global chemical transport models. Being a noble gas, radon is not removed from the atmosphere by dry or wet deposition processes, nor does it become attached to aerosols, and so it is a good tracer for air mass movements. This publication summarizes the findings of a technical meeting jointly sponsored by the IAEA and the World Meteorological Organization, at which experts in the fields of radon exhalation from the ground, radon measurements in air, and atmospheric transport modelling came together to discuss the latest developments. A major focus of the meeting was on moving towards agreed approaches to estimating radon exhalation flux densities, and on improving quality assurance of measurements both of radon exhalation flux densities and of concentrations of radon and radon progeny in the atmosphere.

(162 pp., 88 figs; 2012) • ISBN 978-92-0-123610-4 • STI/PUB/1541 • €38.00
Computer Security at Nuclear Facilities
IAEA Nuclear Security Series No. 17
This publication provides guidance specific to nuclear facilities on implementing a computer security programme and evaluating existing programmes. The use of computer systems to cover an increasing range of functions at nuclear facilities introduces new vulnerabilities that could seriously endanger nuclear security if not addressed in a rigorous and balanced manner. Digital systems are increasingly being introduced in safety, safety related and security systems throughout facilities. Non-availability or malfunction of these systems can seriously impact nuclear safety and security, and potentially facilitate sabotage of the facility and/or theft of material. Computer security must, therefore, be a key component of overall facility security.

Arabic Edition (76 pp., 7 figs; 2013) • ISBN 978-92-0-642210-6 • STI/PUB/1527 • €33.00
English Edition (69 pp., 7 figs; 2011) • ISBN 978-92-0-102509-8 • STI/PUB/1527 • €33.00
French Edition (75 pp., 7 figs; 2011) • ISBN 978-92-0-120110-2 • STI/PUB/1527 • €33.00
Russian Edition (80 pp., 7 figs; 2013) • ISBN 978-92-0-642210-6 • STI/PUB/1527 • €33.00
Spanish Edition (Forthcoming 2013)

Educational Programme in Nuclear Security
IAEA Nuclear Security Series No. 12
Higher education plays an essential role in nuclear security capacity building. It ensures the availability of experts able to provide the necessary competencies for effective national nuclear security oversight of nuclear and other radioactive material and to establish and maintain an appropriate nuclear regime in a State. This guide presents both the theoretical knowledge and the practical skills necessary to meet the requirements described in the international framework for nuclear security. Emphasis is placed on the implementation of these requirements and recommendations in States. On the basis of this guide, a university should be able to develop its own academic programme tailored to suit State specific educational needs in the area of nuclear security and to meet national requirements.

Chinese Edition (170 pp., 1 fig.; 2011) • ISBN 978-92-0-523110-5 • STI/PUB/1439 • €42.00
English Edition (168 pp., 1 fig.; 2010) • ISBN 978-92-0-101710-9 • STI/PUB/1439 • €42.00

Establishing the Nuclear Security Infrastructure for a Nuclear Power Programme
IAEA Nuclear Security Series No. 19
This publication provides guidance on the actions to be taken by a State in implementing an effective nuclear security infrastructure for a nuclear power programme. The topics covered are: development of national policy and strategy; common nuclear security measures; infrastructure issues relating to nuclear and other radioactive material; associated facilities; and cooperation with other States. The guidance provided is intended primarily for use by national policy makers, national legislators, competent authorities, institutions and individuals involved in the establishment, implementation, maintenance or sustainability of the nuclear security infrastructure for a nuclear power programme.

(73 pp., 1 fig.; 2013) • ISBN 978-92-0-138010-4 • STI/PUB/1591 • €29.00

Identification of Vital Areas at Nuclear Facilities
IAEA Nuclear Security Series No. 16
This publication provides detailed guidance with regard to the identification of vital areas at nuclear facilities. It presents a structured approach to identifying those areas that contain equipment, systems and components to be protected against sabotage. The process for selection of a specific set of vital areas to be protected is based on consideration of the potential radiological consequences of sabotage, and on the...
design, operational and safety features of a nuclear facility. The method builds upon safety analysis to develop logic models for sabotage scenarios that could cause unacceptable radiological consequences. The sabotage actions represented in the logic models are linked to the areas from which they can be accomplished. The logic models are then analysed to determine areas that should be protected to prevent these unacceptable radiological consequences. The publication is part of a set of supporting publications in the IAEA Nuclear Security Series with the aim of assisting States in the design, implementation and evaluation of their physical protection systems for nuclear material and nuclear facilities.

(37 pp., 2 figs; 2013) • ISBN 978-92-0-114410-2 • STI/PUB/1242 • €23.00

INPRO Collaborative Project: Proliferation Resistance: Acquisition/Diversification Pathway Analysis (PRADA)

IAEA TECDOC Series No. 1684

This publication contributes to strengthening the proliferation resistance assessment area of the INPRO methodology. The basic principle for this area requires that multiple intrinsic features and extrinsic measures of proliferation resistance be implemented throughout the full life cycle of an innovative nuclear energy system to help ensure that the system will continue to be an unattractive means of acquiring fissile material for a nuclear weapons programme. A typical intrinsic feature is the dilution of plutonium with fission products as found in irradiated material, and a typical extrinsic measure is the placing of nuclear material under international safeguards.


Monitoring for Radioactive Material in International Mail Transported by Public Postal Operators

IAEA Nuclear Security Series No. 3

The illegal transport of conventional explosives and biological material has been observed in public mail and could lead to serious health hazards. In response to Member State requests to establish guidance on detecting the movement of radioactive material in international mail, the IAEA and the Universal Postal Union (UPU) undertook a joint effort to prepare this publication. It considers how radioactive materials in international mail might be detected, how best to monitor for these materials in mail facilities and how to respond appropriately. This publication provides a concise but comprehensive description of the various techniques and equipment used to detect and control radioactive material during mail processing.


English Edition (39 pp., 4 figs; 2006) • ISBN 92-0-100406-0 • STI/PUB/1242 • €23.00

Nuclear Forensics Support

IAEA Nuclear Security Series No. 2

Nuclear scientists have recognized that much can be learned from the analysis of reported cases of illicit trafficking of nuclear and other radioactive material, specifically, what the material has been used for, where it was obtained from (stock, scrap or waste) and whether the amount seized was only a sample of a much more significant quantity. These and many other questions can be answered through detailed technical characterization of seized material samples. The combination of scientific methods used for this purpose is normally referred to as nuclear forensics, which has become an indispensable tool for use in law enforcement investigations of nuclear trafficking. This publication is unique in bringing together for the first time a concise but comprehensive description of the various tools and procedures of nuclear forensic investigations that have been described independently in the scientific literature. It also incorporates the experience accumulated over the past decade by law enforcement agencies and nuclear forensics laboratories confronted with cases of illicit events involving nuclear or other radioactive materials.


English Edition (67 pp., 4 figs; 2006) • ISBN 92-0-100306-4 • STI/PUB/1241 • €26.00

Nuclear Security Culture

IAEA Nuclear Security Series No. 7

This publication defines the basic concepts and elements of nuclear security culture, with the aim of providing Member States with international consensus guidance on planning and implementing a programme to improve nuclear security culture. Particular emphasis is placed on areas such as regulation, government institutions and general public awareness. The report provides an overview of the necessary attributes of an effective nuclear security culture and emphasizes that its success is ultimately dependent on individuals: policy makers, regulators, managers, individual employees and, to a certain extent, members of the general public. Practical methods to assess and improve the effectiveness of security culture are also included.

Arabic Edition (43 pp., 2 figs; 2012) • ISBN 978-92-0-623810-3 • STI/PUB/1347 • €30.00

Chinese Edition (36 pp., 2 figs; 2012) • ISBN 978-92-0-526410-3 • STI/PUB/1347 • €30.00

English Edition (37 pp., 2 figs; 2008) • ISBN 978-92-0-107808-7 • STI/PUB/1347 • €30.00

French Edition (41 pp., 2 figs; 2009) • ISBN 978-92-0-206509-3 • STI/PUB/1347 • €30.00

Nuclear Security Recommendations on Nuclear and Other Radioactive Material out of Regulatory Control

IAEA Nuclear Security Series No. 15

This publication presents recommendations for the nuclear security of nuclear and other
radioactive material that is out of regulatory control. It is based on national experience and practices and guidance publications in the field of security as well as the nuclear security related international instruments. The recommendations include guidance for States with regard to the nuclear security of nuclear and other radioactive material that has been reported as being out of regulatory control as well as of material that is lost, missing or stolen but has not been reported as such, or has been otherwise discovered. In addition, these recommendations adhere to the detection and assessment of alarms and alerts and to a graded response to criminal or unauthorized acts with nuclear security implications.

English Edition (33 pp.; 2011) • ISBN 978-92-0-112210-0 • STI/PUB/1488 • €23.00

Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5)
IAEA Nuclear Security Series No. 13

This publication, Revision 5 of Nuclear Security Recommendation on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225), is intended to provide guidance to States and their competent authorities on how to develop or enhance, implement and maintain a physical protection regime for nuclear material and nuclear facilities, through the establishment or improvement of their capabilities to implement legislative and regulatory programmes. The recommendations presented in this publication reflect a broad consensus among IAEA Member States on the requirements which should be met for the physical protection of nuclear materials and nuclear facilities.

Arabic Edition (60 pp.; 2011) • ISBN 978-92-0-624510-5 • STI/PUB/1487 • €22.00

Objective and Essential Elements of a State’s Nuclear Security Regime
IAEA Nuclear Security Series No. 20

This IAEA Nuclear Security Series publication provides nuclear security fundaments, recommendations, and supporting guidance for Member States to assist them in implementing new nuclear security regimes, or in reviewing
and if necessary strengthening existing ones. The IAEA Nuclear Security Series also serves as guidance for Member States with respect to their activities in relation to binding and non-binding international instruments. The Nuclear Security Fundamentals are the primary publication in the IAEA Nuclear Security Series, and set out the objective of an effective national nuclear security regime and essential elements of such a regime. They are aimed at national policy makers, legislative bodies, competent authorities, institutions, and individuals involved in the establishment, implementation, maintenance or sustainability of a State’s nuclear security regime.

(15 pp.; 2013) • ISBN 978-92-0-137810-1 • STI/PUB/1590 • €20.00

Preventive and Protective Measures against Insider Threats
IAEA Nuclear Security Series No. 8

This Implementing Guide presents a comprehensive methodology for the development of preventive and protective measures against insider threats to nuclear facilities and nuclear material transport operations of all types. Institutional insiders who are privy to the inner workings of security systems present a unique challenge to the establishment of effective control systems for nuclear material. They generally possess access rights which, together with their authority and knowledge of facilities, grant them far greater opportunity than any outsider to bypass dedicated physical protection elements or other provisions such as safety systems and operating procedures. Furthermore, insiders, as trusted persons, are capable of methods of defeat that are not available to outsiders. This publication provides guidance on and measures for reducing these and other risks posed by insiders.

French Edition (29 pp., 2 figs; 2013) • ISBN 978-92-0-236710-4 • STI/PUB/1359 • €20.00

Security in the Transport of Radioactive Material
IAEA Nuclear Security Series No. 9

This publication addresses the vulnerability of radioactive material during transport. Given the international concern over acts of nuclear terrorism, it is imperative to have a well defined plan for the security of sensitive materials during their transport. This publication provides guidance on implementing, maintaining or enhancing a State’s nuclear security regime to protect radioactive material in transport against theft, sabotage or other malicious acts. It will be of use to regulators and to operating personnel engaged in the transport of such material.


Security of Radioactive Sources
IAEA Nuclear Security Series No. 11

There are concerns that terrorist or criminal groups could gain access to high activity radioactive sources and use these sources maliciously. The IAEA is working with Member States to increase control, accounting and security of radioactive sources to prevent their malicious use and the associated potential consequences. Based on extensive input from technical and legal experts, this implementation guide sets forth guidance on the security of sources and will serve as a useful tool for legislators and regulators, physical protection specialists, and facility and transport operators, as well as for law enforcement officers.

A key word index with book titles shown in bold.

<table>
<thead>
<tr>
<th>A</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A System for the Feedback of Experience from Events in Nuclear Installations</td>
<td>15</td>
</tr>
<tr>
<td>Advanced Nuclear Fuels /Experiences and Trends of Manufacturing Technology of</td>
<td>34</td>
</tr>
<tr>
<td>Advanced Reactors /Challenges Related to the Use of Liquid Metal and Molten Salt Coolants in</td>
<td>28</td>
</tr>
<tr>
<td>Advanced Surveillance, Diagnostic and Prognostic Techniques in Monitoring Structures, Systems, and Components in Nuclear Power Plants</td>
<td>27</td>
</tr>
<tr>
<td>Advanced Water Cooled Reactors /Natural Circulation Phenomena and Modelling for</td>
<td>29</td>
</tr>
<tr>
<td>Advances in Airborne and Ground Geophysical Methods for Uranium Exploration</td>
<td>9</td>
</tr>
<tr>
<td>Advances in High Temperature Gas Cooled Reactor Fuel Technology</td>
<td>28, 33</td>
</tr>
<tr>
<td>Advances in Nuclear Power Process Heat Applications</td>
<td>27</td>
</tr>
<tr>
<td>Application of Isotope Techniques for Assessing Nutrient Dynamics in River Basins</td>
<td>9</td>
</tr>
<tr>
<td>Application of Radiotracer Techniques for Interwell Studies</td>
<td>10</td>
</tr>
<tr>
<td>Assessing and Managing Cable Ageing in Nuclear Power Plants</td>
<td>30</td>
</tr>
<tr>
<td>Assessment of Iron Bioavailability in Humans Using Stable Iron Isotope Techniques</td>
<td>4</td>
</tr>
<tr>
<td>Assessment of Nuclear Energy Systems Based on a Closed Nuclear Fuel Cycle with Fast Reactors</td>
<td>26, 32</td>
</tr>
<tr>
<td>Atomic and Plasma–Material Interaction Data for Fusion Vol. 15</td>
<td>37</td>
</tr>
<tr>
<td>Atomic and Plasma–Material Interaction Data for Fusion Vol. 16</td>
<td>37</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmark Analyses on the Natural Circulation Test Performed during the PHENIX End-of-life Experiments</td>
<td>25</td>
</tr>
<tr>
<td>Benchmark Analysis Related to the PBMR-400, PBMM, GT-MHR, HTR-10 and the ASTRRA Critical Facility /Evaluation of High Temperature Gas Cooled Reactor Performance:</td>
<td>30</td>
</tr>
<tr>
<td>Benchmark Analysis: Results from Phases 4 and 6 of a Coordinated Research Project on Updated Codes and Methods to Reduce the Calculation Uncertainties of the LMFR Reactivity Effects /BN-600 MOX Core</td>
<td>33</td>
</tr>
<tr>
<td>BN-600 MOX Core Benchmark Analysis: Results from Phases 4 and 6 of a Coordinated Research Project on Updated Codes and Methods to Reduce the Calculation Uncertainties of the LMFR Reactivity Effects</td>
<td>33</td>
</tr>
<tr>
<td>Body Composition Assessment from Birth to Two Years of Age</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable Ageing in Nuclear Power Plants /Assessing and Managing</td>
<td>30</td>
</tr>
<tr>
<td>Cancer Care: Development and Implementation /Radiotherapy in Palliative</td>
<td>1</td>
</tr>
<tr>
<td>Cancer: Acceptance Testing, Commissioning and Quality Control /Record and Verify Systems for Radiation Treatment of</td>
<td>1</td>
</tr>
<tr>
<td>Carbon Isotope Discrimination /Greater Agronomic Water Use Efficiency in Wheat and Rice Using</td>
<td>6</td>
</tr>
<tr>
<td>Topic</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Challenges Related to the Use of Liquid Metal and Molten Salt Coolants in Advanced Reactors</td>
<td>28</td>
</tr>
<tr>
<td>Clearance Levels /Monitoring for Compliance with Exemption and</td>
<td>22</td>
</tr>
<tr>
<td>Closed Nuclear Fuel Cycle with Fast Reactors /Assessment of Nuclear Energy Systems Based on a</td>
<td>26, 32</td>
</tr>
<tr>
<td>Commissioning for Nuclear Power Plants</td>
<td>15</td>
</tr>
<tr>
<td>Comparison of Heavy Water Reactor Thermalhydraulic Code Predictions with Small Break LOCA Experimental Data</td>
<td>28</td>
</tr>
<tr>
<td>Compliance with Exemption and Clearance Levels /Monitoring for</td>
<td>22</td>
</tr>
<tr>
<td>Compliance with Remediation Criteria for Sites /Monitoring for</td>
<td>13, 22</td>
</tr>
<tr>
<td>Computed Tomography: Diagnostic and Therapy Applications /Quality Assurance Programme for</td>
<td>3</td>
</tr>
<tr>
<td>Computer Security at Nuclear Facilities</td>
<td>12, 42</td>
</tr>
<tr>
<td>Conduct of Operations at Nuclear Power Plants</td>
<td>15</td>
</tr>
<tr>
<td>Contamination /Guidelines for Remediation Strategies to Reduce the Radiological Consequences of Environmental</td>
<td>40</td>
</tr>
<tr>
<td>Control of Goods Containing Small Amounts of Radioactive Material /Exemption from Regulatory</td>
<td>39</td>
</tr>
<tr>
<td>Control of Orphan Sources and Other Radioactive Material in the Metal Recycling and Production Industries</td>
<td>19</td>
</tr>
<tr>
<td>Control over Orphan Sources and Improving Control over Vulnerable Sources /National Strategy for Regaining</td>
<td>19</td>
</tr>
<tr>
<td>Core Benchmark Analysis: Results from Phases 4 and 6 of a Coordinated Research Project on Updated Codes and Methods to Reduce the Calculation Uncertainties of the LMFR Reactivity Effects /BN-600 MOX</td>
<td>33</td>
</tr>
<tr>
<td>Cost Estimation for Research Reactor Decommissioning</td>
<td>26</td>
</tr>
<tr>
<td>Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency</td>
<td>22</td>
</tr>
<tr>
<td>Criticality Safety in the Handling of Fissile Material</td>
<td>19</td>
</tr>
<tr>
<td>Cyclotron Produced Radionuclides: Guidance on Facility Design and Production of [18F]Fluorodeoxyglucose (FDG)</td>
<td>4</td>
</tr>
<tr>
<td>Cyclotron Produced Radionuclides: Operation and Maintenance of Gas and Liquid Targets</td>
<td>4</td>
</tr>
</tbody>
</table>

**D**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decommissioning /Cost Estimation for Research Reactor</td>
<td>26</td>
</tr>
<tr>
<td>Decommissioning /Safety Assessment for</td>
<td>23, 33</td>
</tr>
<tr>
<td>Decommissioning of Nuclear and Radiological Facilities /Policies and Strategies for the</td>
<td>33</td>
</tr>
<tr>
<td>Decommissioning of Nuclear Facilities /Planning, Management and Organizational Aspects in</td>
<td>33</td>
</tr>
<tr>
<td>Dense Magnetized Plasmas</td>
<td>37</td>
</tr>
<tr>
<td>Design Basis Threat /Development, Use and Maintenance of the</td>
<td>42</td>
</tr>
<tr>
<td>Design Features and Operating Experiences of Experimental Fast Reactors</td>
<td>28</td>
</tr>
<tr>
<td>Design, Development and Optimization of a Low-cost System for Digital Industrial Radiology</td>
<td>10</td>
</tr>
<tr>
<td>Design, Manufacturing and Irradiation Behaviour of Fast Reactor Fuel</td>
<td>34</td>
</tr>
<tr>
<td>Deterministic Safety Analysis for Nuclear Power Plants</td>
<td>15</td>
</tr>
<tr>
<td>Development of Novel Adsorbents and Membranes by Radiation-induced Grafting for Selective Separation in Environmental and Industrial Applications</td>
<td>10</td>
</tr>
<tr>
<td>Development of Procedures for in Vivo Dosimetry in Radiotherapy</td>
<td>1</td>
</tr>
<tr>
<td>Development, Use and Maintenance of the Design Basis Threat</td>
<td>42</td>
</tr>
<tr>
<td>Diagnostic Imaging /Justification of Medical Exposure in</td>
<td>2</td>
</tr>
</tbody>
</table>
Dosimetry in Diagnostic Radiology for Paediatric Patients

Educational Programme in Nuclear Security

Efficient Water Management in Water Cooled Reactors

Electric Grid Reliability and Interface with Nuclear Power Plants

Emergency /Criteria for Use in Preparedness and Response for a Nuclear or Radiological


Results of the

Engineering Safety Aspects of the Protection of Nuclear Power Plants against Sabotage

Environmental and Industrial Applications /Development of Novel Adsorbents and Membranes by Radiation-induced Grafting for Selective Separation in

Environmental Contamination /Guidelines for Remediation Strategies to Reduce the Radiological Consequences of


Environmental Remediation Projects /Overcoming Barriers in the Implementation of

Establishing the Nuclear Security Infrastructure for a Nuclear Power Programme

Establishing the Safety Infrastructure for a Nuclear Power Programme

Evaluation of High Temperature Gas Cooled Reactor Performance: Benchmark Analysis Related to the PBMR-400, PBMM, GT-MHR, HTR-10 and the ASTRA Critical Facility

Events in Nuclear Installations / A System for the Feedback of Experience from

Exemption and Clearance Levels /Monitoring for Compliance with

Exemption from Regulatory Control of Goods Containing Small Amounts of Radioactive Material

Experiences and Trends of Manufacturing Technology of Advanced Nuclear Fuels

Experimental Fast Reactors /Design Features and Operating Experiences of

Fast Reactor Fuel /Design, Manufacturing and Irradiation Behaviour of

Fast Reactor Fuel Assemblies — Operational Behaviour /Structural Materials for Liquid Metal Cooled

Fast Reactor Research and Technology Development /Status of

Fast Reactors (Reactors Cooled by Sodium, Lead and Lead-bismuth Eutectic)/Liquid Metal Coolants for

Fast Reactors /Assessment of Nuclear Energy Systems Based on a Closed Nuclear Fuel Cycle with

Fast Reactors /Design Features and Operating Experiences of Experimental

Fast Reactors and Related Fuel Cycles: Challenges and Opportunities (FR09)

Fissile Material /Criticality Safety in the Handling of

Forensics Support /Nuclear

Exemption from Regulatory Control of Goods Containing Small Amounts of Radioactive Material

Experiences and Trends of Manufacturing Technology of Advanced Nuclear Fuels

Experimental Fast Reactors /Design Features and Operating Experiences of
<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Framework for Assessing Dynamic Nuclear Energy Systems for Sustainability</td>
<td>25</td>
</tr>
<tr>
<td>Fuel Behaviour and Modelling under Severe Transient and Loss of Coolant Accident (LOCA) Conditions</td>
<td>34</td>
</tr>
<tr>
<td>Fuel Behaviour Simulation (FUMEX -III)/Improvement of Computer Codes Used for</td>
<td>34</td>
</tr>
<tr>
<td>Fuel Cycles of Future Nuclear Energy Systems /Role of Thorium to Supplement</td>
<td>34</td>
</tr>
<tr>
<td>Fuel Cycles: Challenges and Opportunities (FR09)/Fast Reactors and Related</td>
<td>28, 32</td>
</tr>
<tr>
<td>Fuel Failures /Water Chemistry and Clad Corrosion/Deposition Including</td>
<td>33</td>
</tr>
<tr>
<td>Fuel Modelling at Extended Burnup (FUMEX-II)</td>
<td>34</td>
</tr>
<tr>
<td>Fusion</td>
<td>37</td>
</tr>
<tr>
<td>Fusion: An Integrated Approach /Pathways to Energy from Inertial</td>
<td>37</td>
</tr>
<tr>
<td>G</td>
<td></td>
</tr>
<tr>
<td>Geophysical Methods for Uranium Exploration /Advances in Airborne and Ground</td>
<td>9</td>
</tr>
<tr>
<td>Greater Agronomic Water Use Efficiency in Wheat and Rice Using Carbon Isotope Discrimination</td>
<td>6</td>
</tr>
<tr>
<td>Guidelines for Development, Validation and Routine Control of Industrial Radiation Processes</td>
<td>10</td>
</tr>
<tr>
<td>Guidelines for Remediation Strategies to Reduce the Radiological Consequences of Environmental Contamination</td>
<td>40</td>
</tr>
<tr>
<td>H</td>
<td></td>
</tr>
<tr>
<td>Heavy Water Reactor Thermalhydraulic Code Predictions with Small Break LOCA Experimental Data /Comparison of</td>
<td>28</td>
</tr>
<tr>
<td>High Temperature Gas Cooled Reactor Fuel Technology /Advances in</td>
<td>28, 33</td>
</tr>
<tr>
<td>High Temperature Gas Cooled Reactor Performance: Benchmark Analysis Related to the PBMR-400, PBMM, GT-MHR, HTR-10 and the ASTRA Critical Facility /Evaluation of</td>
<td>30</td>
</tr>
<tr>
<td>Hot Cell Post-irradiation Examination and Poolside Inspection of Nuclear Fuel</td>
<td>32</td>
</tr>
<tr>
<td>Human Resource Development for Introducing and Expanding Nuclear Power Programmes</td>
<td>30</td>
</tr>
<tr>
<td>Humans Using Stable Iron Isotope Techniques /Assessment of Iron Bioavailability in</td>
<td>4</td>
</tr>
<tr>
<td>Hydrogen Production Using Nuclear Energy</td>
<td>25</td>
</tr>
<tr>
<td>Hydrogen Storage and Fuel Cells /Role of Nuclear Based Techniques in Development and Characterization of Materials for</td>
<td>7</td>
</tr>
<tr>
<td>Hydrology, Marine Ecosystems and Climate Change Studies /Isotopes in</td>
<td>9, 40</td>
</tr>
<tr>
<td>I</td>
<td></td>
</tr>
<tr>
<td>Identification of Vital Areas at Nuclear Facilities</td>
<td>13, 42</td>
</tr>
<tr>
<td>Implementation of a Management System for Operating Organizations of Research Reactors</td>
<td>18</td>
</tr>
<tr>
<td>Improvement of Computer Codes Used for Fuel Behaviour Simulation (FUMEX -III)</td>
<td>34</td>
</tr>
<tr>
<td>Industrial Applications /Development of Novel Adsorbents and Membranes by Radiation-induced Grafting for Selective Separation in Environmental and</td>
<td>10</td>
</tr>
<tr>
<td>Industrial Radiation Processes /Guidelines for Development, Validation and Routine Control of</td>
<td>10</td>
</tr>
<tr>
<td>Inertial Fusion: An Integrated Approach /Pathways to Energy from</td>
<td>37</td>
</tr>
<tr>
<td>INPRO Collaborative Project: Proliferation Resistance: Acquisition/Diversion Pathway Analysis (PRADA)</td>
<td>43</td>
</tr>
<tr>
<td>Instrumentation for Digital Nuclear Spectroscopy</td>
<td>7</td>
</tr>
<tr>
<td>International Safeguards in Nuclear Facility Design and Construction</td>
<td>25, 38</td>
</tr>
<tr>
<td>Interwell Studies /Application of Radiotracer Techniques for</td>
<td>10</td>
</tr>
<tr>
<td>Invitation and Evaluation of Bids for Nuclear Power Plants</td>
<td>26</td>
</tr>
<tr>
<td>Index</td>
<td>Title</td>
</tr>
<tr>
<td>-------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>19</td>
<td>National Strategy for Regaining Control over Orphan Sources and Improving Control over Vulnerable Sources</td>
</tr>
<tr>
<td>29</td>
<td>Natural Circulation Phenomena and Modelling for Advanced Water Cooled Reactors</td>
</tr>
<tr>
<td>29</td>
<td>Near Term Deployment /Nuclear Reactor Technology Assessment for</td>
</tr>
<tr>
<td>7</td>
<td>Neutron Generators for Analytical Purposes</td>
</tr>
<tr>
<td>10</td>
<td>Neutron Transmutation Doping of Silicon at Research Reactors</td>
</tr>
<tr>
<td>5</td>
<td>Non-HEU Production Technologies for Molybdenum-99 and Technetium-99m</td>
</tr>
<tr>
<td>21, 23</td>
<td>NORM Residue Management in the Titanium Dioxide and Related Industries/Radiation Protection and Management of Materials</td>
</tr>
<tr>
<td>21, 36</td>
<td>NORM Residues in the Phosphate Industry /Radiation Protection and Management of</td>
</tr>
<tr>
<td>13, 43</td>
<td>Nuclear and Other Radioactive Material out of Regulatory Control/Nuclear Security Recommendations on the Use of Radioactive Materials</td>
</tr>
<tr>
<td>33</td>
<td>Nuclear Based Techniques in Development and Characterization of Materials for Hydrogen Storage and Fuel Cells /Role of Nuclear Fuels</td>
</tr>
<tr>
<td>2</td>
<td>Nuclear Cardiology: Guidance and Recommendations for Implementation in Developing Countries</td>
</tr>
<tr>
<td>2</td>
<td>Nuclear Cardiology: Its Role in Cost Effective Care</td>
</tr>
<tr>
<td>5, 8</td>
<td>Nuclear Data for the Production of Therapeutic Radionuclides</td>
</tr>
<tr>
<td>25</td>
<td>Nuclear Energy /Hydrogen Production Using</td>
</tr>
<tr>
<td>34</td>
<td>Nuclear Energy Systems /Role of Thorium to Supplement Fuel Cycles of Future</td>
</tr>
<tr>
<td>26, 32</td>
<td>Nuclear Energy Systems Based on a Closed Nuclear Fuel Cycle with Fast Reactors /Assessment of Nuclear Energy Systems</td>
</tr>
<tr>
<td>44</td>
<td>Nuclear Facilities (INFCIRC/225/Revision 5)/Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities</td>
</tr>
<tr>
<td>12, 42</td>
<td>Nuclear Facilities /Computer Security at</td>
</tr>
<tr>
<td>13, 42</td>
<td>Nuclear Facilities /Identification of Vital Areas at</td>
</tr>
<tr>
<td>33</td>
<td>Nuclear Facilities /Planning, Management and Organizational Aspects in Decommissioning of Nuclear Facilities</td>
</tr>
<tr>
<td>25, 38</td>
<td>Nuclear Facility Design and Construction /International Safeguards in Nuclear Facilities and Nuclear Facilities</td>
</tr>
<tr>
<td>43</td>
<td>Nuclear Forensics Support</td>
</tr>
<tr>
<td>32</td>
<td>Nuclear Fuel /Hot Cell Post-irradiation Examination and Poolside Inspection of Nuclear Fuel</td>
</tr>
<tr>
<td>35</td>
<td>Nuclear Fuel /Management and Storage of Research Reactor Spent</td>
</tr>
<tr>
<td>26, 32</td>
<td>Nuclear Fuel Cycle with Fast Reactors /Assessment of Nuclear Energy Systems Based on a Closed Nuclear Fuel Cycle</td>
</tr>
<tr>
<td>34</td>
<td>Nuclear Fuels /Experiences and Trends of Manufacturing Technology of Advanced Nuclear Fuels</td>
</tr>
<tr>
<td>31</td>
<td>Nuclear Industry Organizations /Risk Management of Knowledge Loss in Nuclear Industry Organizations</td>
</tr>
<tr>
<td>15</td>
<td>Nuclear Installations /A System for the Feedback of Experience from Events in Nuclear Installations</td>
</tr>
<tr>
<td>17</td>
<td>Nuclear Installations /Volcanic Hazards in Site Evaluation for Nuclear Installations</td>
</tr>
<tr>
<td>44</td>
<td>Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5)/Nuclear Security Recommendations on Physical Protection of Nuclear Facilities and Nuclear Facilities</td>
</tr>
<tr>
<td>3</td>
<td>Nuclear Medicine Imaging: Concepts, Requirements and Methods /Quantitative Nuclear Medicine Imaging</td>
</tr>
<tr>
<td>22</td>
<td>Nuclear or Radiological Emergency /Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency</td>
</tr>
<tr>
<td>31</td>
<td>Nuclear Organizations /Managing Organizational Change in Nuclear Organizations</td>
</tr>
<tr>
<td>13, 16</td>
<td>Nuclear Power Plant /Licensing the First</td>
</tr>
<tr>
<td>Topic</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Nuclear Power Plant Construction: Guidelines and Experience</td>
<td>27</td>
</tr>
<tr>
<td>Project Management in Nuclear Power Plant Projects</td>
<td>14</td>
</tr>
<tr>
<td>Safety Culture in Pre-operational Phases of Nuclear Power Plants</td>
<td>14</td>
</tr>
<tr>
<td>Advanced Surveillance, Diagnostic and Prognostic Techniques in</td>
<td>27</td>
</tr>
<tr>
<td>Monitoring Structures, Systems, and Components in</td>
<td></td>
</tr>
<tr>
<td>Nuclear Power Plants /Assessing and Managing Cable Ageing</td>
<td>30</td>
</tr>
<tr>
<td>Commissioning for</td>
<td>15</td>
</tr>
<tr>
<td>Conduct of Operations at</td>
<td>15</td>
</tr>
<tr>
<td>Deterministic Safety Analysis for</td>
<td>15</td>
</tr>
<tr>
<td>Electric Grid Reliability and Interface with</td>
<td>26</td>
</tr>
<tr>
<td>Nuclear Power Plants /Invitation and Evaluation of Bids for</td>
<td>26</td>
</tr>
<tr>
<td>Managing Siting Activities for</td>
<td>26</td>
</tr>
<tr>
<td>Nuclear Power Plants /Periodic Safety Review for</td>
<td>16</td>
</tr>
<tr>
<td>Nuclear Power Plants against Sabotage /Engineering Safety Aspects of</td>
<td>16</td>
</tr>
<tr>
<td>the Protection of</td>
<td></td>
</tr>
<tr>
<td>Nuclear Power Plants: Best Practices /Low Level Event and Near Miss</td>
<td>16</td>
</tr>
<tr>
<td>Process for</td>
<td></td>
</tr>
<tr>
<td>Nuclear Power Plants: Commissioning and Operation /Safety of</td>
<td>16</td>
</tr>
<tr>
<td>Nuclear Power Plants: Design /Safety of</td>
<td>17</td>
</tr>
<tr>
<td>Process Heat Applications /Advances in</td>
<td>27</td>
</tr>
<tr>
<td>Nuclear Power Programme /Establishing the Nuclear Security Infrastructure for a</td>
<td>12, 42</td>
</tr>
<tr>
<td>Nuclear Power Programme /Establishing the Safety Infrastructure for a</td>
<td>12</td>
</tr>
<tr>
<td>Nuclear Power Programmes /Human Resource Development for Introducing and Expanding</td>
<td>30</td>
</tr>
<tr>
<td>Options for Management of Spent Fuel and Radioactive Waste for Countries Developing New</td>
<td>35</td>
</tr>
<tr>
<td>Nuclear Power Reactors in the World</td>
<td>25</td>
</tr>
<tr>
<td>Nuclear Power Stations in Member States in 2011/Operating Experience</td>
<td>27</td>
</tr>
<tr>
<td>with</td>
<td></td>
</tr>
<tr>
<td>Nuclear Reactor Technology Assessment for Near Term Deployment</td>
<td>29</td>
</tr>
<tr>
<td>Nuclear Research and Development Organizations /Knowledge Management</td>
<td>30</td>
</tr>
<tr>
<td>for</td>
<td></td>
</tr>
<tr>
<td>Nuclear Security /Educational Programme in</td>
<td>42</td>
</tr>
<tr>
<td>Nuclear Security Culture</td>
<td>43</td>
</tr>
<tr>
<td>Nuclear Security Infrastructure for a Nuclear Power Programme /Establishing the</td>
<td>12, 42</td>
</tr>
<tr>
<td>Nuclear Security Recommendations on Nuclear and Other Radioactive</td>
<td>13, 43</td>
</tr>
<tr>
<td>Material out of Regulatory Control</td>
<td></td>
</tr>
<tr>
<td>Nuclear Security Recommendations on Physical Protection of Nuclear</td>
<td>44</td>
</tr>
<tr>
<td>Material and Nuclear Facilities (INFCIRC/225/Revision 5)</td>
<td></td>
</tr>
<tr>
<td>Nuclear Security Recommendations on Radioactive Material and</td>
<td>14, 44</td>
</tr>
<tr>
<td>Associated Facilities</td>
<td></td>
</tr>
<tr>
<td>Nuclear Security Regime /Objective and Essential Elements of a State’s</td>
<td>44</td>
</tr>
<tr>
<td>Nuclear Security Systems and Measures for Major Public Events</td>
<td>14, 44</td>
</tr>
<tr>
<td>Nuclear Spectroscopy /Instrumentation for Digital</td>
<td>7</td>
</tr>
<tr>
<td>Objective and Essential Elements of a State’s Nuclear Security Regime</td>
<td>44</td>
</tr>
<tr>
<td>Operating Experience with Nuclear Power Stations in Member States in 2011</td>
<td>27</td>
</tr>
</tbody>
</table>
Options for Management of Spent Fuel and Radioactive Waste for Countries Developing New Nuclear Power Programmes

Orphan Sources and Improving Control over Vulnerable Sources /National Strategy for Regaining Control over
Orphan Sources and Other Radioactive Material in the Metal Recycling and Production Industries /Control of
Overcoming Barriers in the Implementation of Environmental Remediation Projects

P

Passive Safety Systems (AWCR)/Advanced Water Cooled Reactor Case Studies in Support of
Pathways to Energy from Inertial Fusion: An Integrated Approach
Peer Review of the Radioactive Waste Management Activities of COVRA, Netherlands
Performance Assessment of Passive Gaseous Provisions (PGAP)
Periodic Safety Review for Nuclear Power Plants
Phosphate Industry /Radiation Protection and Management of NORM Residues in the
Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5)/Nuclear Security Recommendations on
Planning, Management and Organizational Aspects in Decommissioning of Nuclear Facilities
Policies and Strategies for the Decommissioning of Nuclear and Radiological Facilities
Practical Guidance on Peptide Receptor Radionuclide Therapy (PRRNT) in Neuroendocrine Tumours
Predisposal Management of Radioactive Waste /The Safety Case and Safety Assessment for the
Preparedness and Response for a Nuclear or Radiological Emergency /Criteria for Use in
Preparing for Future Verification Challenges
Preventive and Protective Measures against Insider Threats
Process Heat Applications /Advances in Nuclear Power
Project Management in Nuclear Power Plant Construction: Guidelines and Experience
Proliferation Resistance: Acquisition/Diversion Pathway Analysis (PRADA)/INPRO Collaborative Project: Protection of Nuclear Power Plants against Sabotage /Engineering Safety Aspects of the
Protective Measures against Insider Threats /Preventive and

Q

Quality Assurance Programme for Computed Tomography: Diagnostic and Therapy Applications
Quality Control for Expanded Tsetse Production, Sterilization and Field Application
Quantitative Nuclear Medicine Imaging: Concepts, Requirements and Methods

R

Radiation Processes /Guidelines for Development, Validation and Routine Control of Industrial
Radiation Protection and Management of NORM Residues in the Phosphate Industry
Radiation Protection and NORM Residue Management in the Titanium Dioxide and Related Industries
Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards
Radiation Protection in Paediatric Radiology
<table>
<thead>
<tr>
<th>Title</th>
<th>Page(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation Safety in Industrial Radiography</td>
<td>21</td>
</tr>
<tr>
<td>Radiation Sources: International Basic Safety Standards / Radiation Protection and Safety of</td>
<td>14</td>
</tr>
<tr>
<td>Radiation Treatment of Cancer: Acceptance Testing, Commissioning and Quality Control / Record and Verify Systems for</td>
<td>1</td>
</tr>
<tr>
<td>Radiation-induced Grafting for Selective Separation in Environmental and Industrial Applications / Development of Novel Adsorbents and Membranes by</td>
<td>10</td>
</tr>
<tr>
<td>Radioactive Material / Exemption from Regulatory Control of Goods Containing Small Amounts of</td>
<td>39</td>
</tr>
<tr>
<td>Radioactive Material / Security in the Transport of</td>
<td>45</td>
</tr>
<tr>
<td>Radioactive Material and Associated Facilities / Nuclear Security Recommendations on</td>
<td>14, 44</td>
</tr>
<tr>
<td>Radioactive Material in International Mail Transported by Public Postal Operators / Monitoring for</td>
<td>43</td>
</tr>
<tr>
<td>Radioactive Material in the Metal Recycling and Production Industries / Control of Orphan Sources and Other</td>
<td>19</td>
</tr>
<tr>
<td>Radioactive Material out of Regulatory Control / Nuclear Security Recommendations on Nuclear and Other</td>
<td>13, 43</td>
</tr>
<tr>
<td>Radioactive Residues / Remediation of Land Affected by</td>
<td>36, 40</td>
</tr>
<tr>
<td>Radioactive Sources / Security of</td>
<td>45</td>
</tr>
<tr>
<td>Radioactive Substances in the Primary Circuit of Water Cooled Reactors / Modelling of Transport of</td>
<td>29</td>
</tr>
<tr>
<td>Radioactive Waste — Results of a Coordinated Research Project / The Behaviour of Cementitious Materials in Long Term Storage and Disposal of</td>
<td>36</td>
</tr>
<tr>
<td>Radioactive Waste / Disposal of</td>
<td>22</td>
</tr>
<tr>
<td>Radioactive Waste / The Safety Case and Safety Assessment for the Disposal of</td>
<td>23</td>
</tr>
<tr>
<td>Radioactive Waste / The Safety Case and Safety Assessment for the Predisposal Management of</td>
<td>24</td>
</tr>
<tr>
<td>Radioactive Waste for Countries Developing New Nuclear Power Programmes / Options for Management of Spent Fuel and</td>
<td>35</td>
</tr>
<tr>
<td>Radioactive Waste Management / Mobile Processing Systems for</td>
<td>35</td>
</tr>
<tr>
<td>Radioactive Waste Management Activities of COVRA, Netherlands / Peer Review of the</td>
<td>22</td>
</tr>
<tr>
<td>Radiography / Radiation Safety in Industrial</td>
<td>21</td>
</tr>
<tr>
<td>Radiological Consequences of Environmental Contamination / Guidelines for Remediation Strategies to Reduce the</td>
<td>40</td>
</tr>
<tr>
<td>Radiological Emergency / Criteria for Use in Preparedness and Response for a Nuclear or</td>
<td>22</td>
</tr>
<tr>
<td>Radiological Facilities / Policies and Strategies for the Decommissioning of Nuclear and</td>
<td>33</td>
</tr>
<tr>
<td>Radiology / Radiation Protection in Paediatric</td>
<td>3, 21</td>
</tr>
<tr>
<td>Radiology for Paediatric Patients / Dosimetry in Diagnostic</td>
<td>2</td>
</tr>
<tr>
<td>Radiology Physics: A Handbook for Teachers and Students / Diagnostic</td>
<td>2</td>
</tr>
<tr>
<td>Radionuclide Therapy (PRRNT) in Neuroendocrine Tumours / Practical Guidance on Peptide Receptor</td>
<td>1</td>
</tr>
<tr>
<td>Radionuclides / Nuclear Data for the Production of Therapeutic</td>
<td>5, 8</td>
</tr>
<tr>
<td>Radionuclides: Guidance on Facility Design and Production of [18F] Fluorodeoxyglucose (FDG) / Cyclotron Produced</td>
<td>4</td>
</tr>
<tr>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Radionuclides: Operation and Maintenance of Gas and Liquid Targets</td>
<td>4</td>
</tr>
<tr>
<td>Radiotherapy /Development of Procedures for in Vivo Dosimetry in</td>
<td>1</td>
</tr>
<tr>
<td>Radiotherapy in Palliative Cancer Care: Development and Implementation</td>
<td>1</td>
</tr>
<tr>
<td>Radiotracer Generators for Industrial Applications</td>
<td>11</td>
</tr>
<tr>
<td>Radiotracer Techniques for Interwell Studies /Application of</td>
<td>10</td>
</tr>
<tr>
<td>Radon and Radon Progeny Applied to Climate and Air Quality Studies /Sources and Measurements of</td>
<td>41</td>
</tr>
<tr>
<td>Radon Releases from NORM Residues /Measurement and Calculation of</td>
<td>7</td>
</tr>
<tr>
<td>Reactor Fuel /Design, Manufacturing and Irradiation Behaviour of Fast</td>
<td>34</td>
</tr>
<tr>
<td>Reactor Fuel Technology /Advances in High Temperature Gas Cooled</td>
<td>28, 33</td>
</tr>
<tr>
<td>Record and Verify Systems for Radiation Treatment of Cancer: Acceptance Testing, Commissioning and Quality Control</td>
<td>1</td>
</tr>
<tr>
<td>Regulatory Control of Goods Containing Small Amounts of Radioactive Material /Exemption from</td>
<td>39</td>
</tr>
<tr>
<td>Remediation Criteria for Sites /Monitoring for Compliance with</td>
<td>13, 22</td>
</tr>
<tr>
<td>Remediation of Land Affected by Radioactive Residues</td>
<td>36, 40</td>
</tr>
<tr>
<td>Remediation Projects /Overcoming Barriers in the Implementation of Environmental</td>
<td>32, 40</td>
</tr>
<tr>
<td>Remediation Strategies to Reduce the Radiological Consequences of Environmental Contamination /Guidelines for</td>
<td>40</td>
</tr>
<tr>
<td>Research Reactor Decommissioning /Cost Estimation for</td>
<td>26</td>
</tr>
<tr>
<td>Research Reactor Project /Specific Considerations and Milestones for a</td>
<td>27</td>
</tr>
<tr>
<td>Research Reactor Spent Nuclear Fuel /Management and Storage of</td>
<td>35</td>
</tr>
<tr>
<td>Research Reactors /Implementation of a Management System for Operating Organizations of</td>
<td>18</td>
</tr>
<tr>
<td>Research Reactors /Neutron Transmutation Doping of Silicon at</td>
<td>10</td>
</tr>
<tr>
<td>Research Reactors /Safety in the Utilization and Modification of</td>
<td>18</td>
</tr>
<tr>
<td>Research Reactors /Use of a Graded Approach in the Application of the Safety Requirements for</td>
<td>19</td>
</tr>
<tr>
<td>Research Reactors and Preparation of the Safety Analysis Report /Safety Assessment for</td>
<td>18</td>
</tr>
<tr>
<td>Research Reactors: Safe Management and Effective Utilization</td>
<td>7, 18</td>
</tr>
<tr>
<td>Review of Sealed Source Designs and Manufacturing Techniques Affecting Disused Source Management</td>
<td>36</td>
</tr>
<tr>
<td>Risk Management of Knowledge Loss in Nuclear Industry Organizations</td>
<td>31</td>
</tr>
<tr>
<td>Role of Nuclear Based Techniques in Development and Characterization of Materials for Hydrogen Storage and Fuel Cells</td>
<td>7</td>
</tr>
<tr>
<td>Role of Thorium to Supplement Fuel Cycles of Future Nuclear Energy Systems</td>
<td>34</td>
</tr>
<tr>
<td>Roles and Responsibilities, and Education and Training Requirements for Clinically Qualified Medical Physicists</td>
<td>3</td>
</tr>
<tr>
<td>S</td>
<td>Sabotage / Engineering Safety Aspects of the Protection of Nuclear Power Plants against Sabotage / Engineering</td>
</tr>
<tr>
<td>Safeguards / Legal Framework for IAEA</td>
<td>24</td>
</tr>
<tr>
<td>Safety Analysis for Nuclear Power Plants / Deterministic</td>
<td>15</td>
</tr>
<tr>
<td>Safety Analysis Report / Safety Assessment for Research Reactors and Preparation of the Safety Assessment for Decommissioning</td>
<td>18</td>
</tr>
<tr>
<td>Safety Aspects of the Protection of Nuclear Power Plants against Sabotage / Engineering</td>
<td>16</td>
</tr>
<tr>
<td>Safety Assessment for Decommissioning</td>
<td>23, 33</td>
</tr>
<tr>
<td>Safety Assessment for Research Reactors and Preparation of the Safety Analysis Report</td>
<td>18</td>
</tr>
<tr>
<td>Safety Culture in Pre-operational Phases of Nuclear Power Plant Projects</td>
<td>14</td>
</tr>
<tr>
<td>Safety in the Utilization and Modification of Research Reactors</td>
<td>18</td>
</tr>
<tr>
<td>Safety Infrastructure for a Nuclear Power Programme / Establishing the Safety of Nuclear Power Plants: Commissioning and Operation</td>
<td>16</td>
</tr>
<tr>
<td>Safety of Nuclear Power Plants: Design</td>
<td>17</td>
</tr>
<tr>
<td>Security in the Transport of Radioactive Material</td>
<td>20</td>
</tr>
<tr>
<td>Security of Radioactive Sources</td>
<td>36</td>
</tr>
<tr>
<td>Security Regime / Objective and Essential Elements of a State’s Nuclear</td>
<td>44</td>
</tr>
<tr>
<td>Severe Transient and Loss of Coolant Accident (LOCA) Conditions / Fuel Behaviour and Modelling under Site Evaluation for Nuclear Installations / Volcanic Hazards in</td>
<td>34</td>
</tr>
<tr>
<td>Sources and Measurements of Radon and Radon Progeny Applied to Climate and Air Quality Studies</td>
<td>41</td>
</tr>
<tr>
<td>Specific Considerations and Milestones for a Research Reactor Project</td>
<td>27</td>
</tr>
<tr>
<td>Spent Fuel Performance Assessment and Research: Final Report of a Coordinated Research Project (SPAR-II)</td>
<td>35</td>
</tr>
<tr>
<td>Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS)</td>
<td>3</td>
</tr>
<tr>
<td>Status of Fast Reactor Research and Technology Development</td>
<td>30</td>
</tr>
<tr>
<td>Storage of Spent Nuclear Fuel</td>
<td>23</td>
</tr>
<tr>
<td>Structural Materials for Liquid Metal Cooled Fast Reactor Fuel Assemblies — Operational Behaviour</td>
<td>35</td>
</tr>
<tr>
<td>Sustainability / Framework for Assessing Dynamic Nuclear Energy Systems for</td>
<td>25</td>
</tr>
<tr>
<td>T</td>
<td>Technology Development / Status of Fast Reactor Research and</td>
</tr>
<tr>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>The Behaviour of Cementitious Materials in Long Term Storage and Disposal of Radioactive Waste — Results of a Coordinated Research Project</td>
<td>36</td>
</tr>
<tr>
<td>The Management System for Facilities and Activities</td>
<td>17</td>
</tr>
<tr>
<td>The Safety Case and Safety Assessment for the Disposal of Radioactive Waste</td>
<td>23</td>
</tr>
<tr>
<td>The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste</td>
<td>24</td>
</tr>
<tr>
<td>Therapeutic Radionuclides /Nuclear Data for the Production of</td>
<td>5, 8</td>
</tr>
<tr>
<td>Thermalhydraulic Code Predictions with Small Break LOCA Experimental Data /Comparison of Heavy Water Reactor</td>
<td>28</td>
</tr>
<tr>
<td>Transport of Radioactive Material /Security in the</td>
<td>45</td>
</tr>
<tr>
<td>Transport of Radioactive Substances in the Primary Circuit of Water Cooled Reactors /Modelling of</td>
<td>29</td>
</tr>
<tr>
<td>Tsetse Production, Sterilization and Field Application /Quality Control for Expanded</td>
<td>6</td>
</tr>
<tr>
<td>U</td>
<td></td>
</tr>
<tr>
<td>Uranium Exploration /Advances in Airborne and Ground Geophysical Methods for</td>
<td>9</td>
</tr>
<tr>
<td>Use of a Graded Approach in the Application of the Safety Requirements for Research Reactors</td>
<td>19</td>
</tr>
<tr>
<td>Use of External Experts by the Regulatory Body</td>
<td>24</td>
</tr>
<tr>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Verification Challenges /Preparing for Future</td>
<td>38</td>
</tr>
<tr>
<td>Vivo Dosimetry in Radiotherapy /Development of Procedures for in</td>
<td>1</td>
</tr>
<tr>
<td>Volcanic Hazards in Site Evaluation for Nuclear Installations</td>
<td>17</td>
</tr>
<tr>
<td>W</td>
<td></td>
</tr>
<tr>
<td>Waste Management /Mobile Processing Systems for Radioactive</td>
<td>35</td>
</tr>
<tr>
<td>Water Chemistry and Clad Corrosion/Deposition Including Fuel Failures</td>
<td>33</td>
</tr>
<tr>
<td>Water Cooled Reactors /Efficient Water Management in</td>
<td>28</td>
</tr>
<tr>
<td>Water Cooled Reactors /Modelling of Transport of Radioactive Substances in the Primary Circuit of</td>
<td>29</td>
</tr>
<tr>
<td>Water Cooled Reactors /Natural Circulation Phenomena and Modelling for Advanced</td>
<td>29</td>
</tr>
<tr>
<td>Water Management in Water Cooled Reactors /Efficient</td>
<td>28</td>
</tr>
<tr>
<td>Water Use Efficiency in Wheat and Rice Using Carbon Isotope Discrimination /Greater Agronomic</td>
<td>6</td>
</tr>
</tbody>
</table>
### Atomic and Plasma–Material Interaction Data for Fusion

<table>
<thead>
<tr>
<th>Title</th>
<th>Volume</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic and Plasma–Material Interaction Data for Fusion</td>
<td>Vol. 15</td>
<td>37</td>
</tr>
<tr>
<td>Atomic and Plasma–Material Interaction Data for Fusion</td>
<td>Vol. 16</td>
<td>37</td>
</tr>
</tbody>
</table>

### IAEA Human Health Reports Series

<table>
<thead>
<tr>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiotherapy in Palliative Cancer Care: Development and Implementation</td>
<td>1</td>
</tr>
<tr>
<td>Record and Verify Systems for Radiation Treatment of Cancer: Acceptance Testing, Commissioning and Quality Control</td>
<td>1</td>
</tr>
<tr>
<td>Development of Procedures for in Vivo Dosimetry in Radiotherapy</td>
<td>1</td>
</tr>
<tr>
<td>Quantitative Nuclear Medicine Imaging: Concepts, Requirements and Methods</td>
<td>3</td>
</tr>
</tbody>
</table>

### IAEA Human Health Series

<table>
<thead>
<tr>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear Cardiology: Its Role in Cost Effective Care</td>
<td>2</td>
</tr>
<tr>
<td>Quality Assurance Programme for Computed Tomography: Diagnostic and Therapy Applications</td>
<td>3</td>
</tr>
<tr>
<td>Practical Guidance on Peptide Receptor Radionuclide Therapy (PRRNT) in Neuroendocrine Tumours</td>
<td>1</td>
</tr>
<tr>
<td>Assessment of Iron Bioavailability in Humans Using Stable Iron Isotope Techniques</td>
<td>4</td>
</tr>
<tr>
<td>Body Composition Assessment from Birth to Two Years of Age</td>
<td>4</td>
</tr>
<tr>
<td>Nuclear Cardiology: Guidance and Recommendations for Implementation in Developing Countries</td>
<td>2</td>
</tr>
<tr>
<td>Dosimetry in Diagnostic Radiology for Paediatric Patients</td>
<td>2</td>
</tr>
<tr>
<td>Roles and Responsibilities, and Education and Training Requirements for Clinically Qualified Medical Physicists</td>
<td>3</td>
</tr>
</tbody>
</table>

### IAEA International Law Series

<table>
<thead>
<tr>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
</table>

### IAEA Nuclear Energy Series

<table>
<thead>
<tr>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advances in Airborne and Ground Geophysical Methods for Uranium Exploration</td>
<td>9</td>
</tr>
<tr>
<td>Role of Thorium to Supplement Fuel Cycles of Future Nuclear Energy Systems</td>
<td>34</td>
</tr>
<tr>
<td>Structural Materials for Liquid Metal Cooled Fast Reactor Fuel Assemblies — Operational Behaviour</td>
<td>35</td>
</tr>
<tr>
<td>Non-HEU Production Technologies for Molybdenum-99 and Technetium-99m</td>
<td>5</td>
</tr>
</tbody>
</table>
IAEA Nuclear Energy Series No. NG-T-1.1 Managing Organizational Change in Nuclear Organizations 31
IAEA Nuclear Energy Series No. NG-T-3.7 Managing Siting Activities for Nuclear Power Plants 26
IAEA Nuclear Energy Series No. NG-T-3.8 Electric Grid Reliability and Interface with Nuclear Power Plants 26
IAEA Nuclear Energy Series No. NG-T-3.9 Invitation and Evaluation of Bids for Nuclear Power Plants 26
IAEA Nuclear Energy Series No. NP-T-1.6 Liquid Metal Coolants for Fast Reactors (Reactors Cooled by Sodium, Lead and Lead-bismuth Eutectic) 29
IAEA Nuclear Energy Series No. NP-T-1.9 Design Features and Operating Experiences of Experimental Fast Reactors 28
IAEA Nuclear Energy Series No. NP-T-1.10 Nuclear Reactor Technology Assessment for Near Term Deployment 29
IAEA Nuclear Energy Series No. NP-T-1.14 Framework for Assessing Dynamic Nuclear Energy Systems for Sustainability 25
IAEA Nuclear Energy Series No. NP-T-2.6 Efficient Water Management in Water Cooled Reactors 28
IAEA Nuclear Energy Series No. NP-T-2.7 Project Management in Nuclear Power Plant Construction: Guidelines and Experience 27
IAEA Nuclear Energy Series No. NP-T-2.8 International Safeguards in Nuclear Facility Design and Construction 25, 38
IAEA Nuclear Energy Series No. NP-T-3.6 Assessing and Managing Cable Ageing in Nuclear Power Plants 30
IAEA Nuclear Energy Series No. NP-T-3.14 Advanced Surveillance, Diagnostic and Prognostic Techniques in Monitoring Structures, Systems, and Components in Nuclear Power Plants 27
IAEA Nuclear Energy Series No. NP-T-4.2 Hydrogen Production Using Nuclear Energy 25
IAEA Nuclear Energy Series No. NP-T-5.1 Specific Considerations and Milestones for a Research Reactor Project 27
IAEA Nuclear Energy Series No. NW-G-2.1 Policies and Strategies for the Decommissioning of Nuclear and Radiological Facilities 33
IAEA Nuclear Energy Series No. NW-T-1.8 Mobile Processing Systems for Radioactive Waste Management 35
IAEA Nuclear Energy Series No. NW-T-1.24 Options for Management of Spent Fuel and Radioactive Waste for Countries Developing New Nuclear Power Programmes 35
IAEA Nuclear Energy Series No. NW-T-2.4 Cost Estimation for Research Reactor Decommissioning 26
IAEA Nuclear Energy Series No. NW-T-3.4 Overcoming Barriers in the Implementation of Environmental Remediation Projects 32, 40

IAEA Nuclear Security Series

IAEA Nuclear Security Series No. 2 Nuclear Forensics Support 43
IAEA Nuclear Security Series No. 3 Monitoring for Radioactive Material in International Mail Transported by Public Postal Operators 43
IAEA Nuclear Security Series No. 4 Engineering Safety Aspects of the Protection of Nuclear Power Plants against Sabotage 16
IAEA Nuclear Security Series No. 7 Nuclear Security Culture 43
IAEA Nuclear Security Series No. 8 Preventive and Protective Measures against Insider Threats 45
IAEA Nuclear Security Series No. 9 Security in the Transport of Radioactive Material 45
IAEA Nuclear Security Series No. 10 Development, Use and Maintenance of the Design Basis Threat 42
IAEA Nuclear Security Series No. 11 Security of Radioactive Sources 45
IAEA Nuclear Security Series No. 12 Educational Programme in Nuclear Security 42
IAEA Nuclear Security Series No. 13 Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5) 44
IAEA Nuclear Security Series No. 14 Nuclear Security Recommendations on Radioactive Material and Associated Facilities 14, 44
<table>
<thead>
<tr>
<th>IAEA Nuclear Security Series No. 15</th>
<th>Nuclear Security Recommendations on Nuclear and Other Radioactive Material out of Regulatory Control</th>
<th>13, 43</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAEA Nuclear Security Series No. 16</td>
<td>Identification of Vital Areas at Nuclear Facilities</td>
<td>13, 42</td>
</tr>
<tr>
<td>IAEA Nuclear Security Series No. 17</td>
<td>Computer Security at Nuclear Facilities</td>
<td>12, 42</td>
</tr>
<tr>
<td>IAEA Nuclear Security Series No. 18</td>
<td>Nuclear Security Systems and Measures for Major Public Events</td>
<td>14, 44</td>
</tr>
<tr>
<td>IAEA Nuclear Security Series No. 19</td>
<td>Establishing the Nuclear Security Infrastructure for a Nuclear Power Programme</td>
<td>12, 42</td>
</tr>
<tr>
<td>IAEA Nuclear Security Series No. 20</td>
<td>Objective and Essential Elements of a State’s Nuclear Security Regime</td>
<td>44</td>
</tr>
</tbody>
</table>

**IAEA Radiation Technology Reports Series**

<table>
<thead>
<tr>
<th>IAEA Radiation Technology Reports No. 1</th>
<th>Neutron Generators for Analytical Purposes</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAEA Radiation Technology Reports No. 2</td>
<td>Design, Development and Optimization of a Low-cost System for Digital Industrial Radiology</td>
<td>10</td>
</tr>
<tr>
<td>IAEA Radiation Technology Reports No. 3</td>
<td>Development of Novel Adsorbents and Membranes by Radiation-induced Grafting for Selective Separation in Environmental and Industrial Applications</td>
<td>10</td>
</tr>
</tbody>
</table>

**IAEA Radiation Technology Series**

<table>
<thead>
<tr>
<th>IAEA Radiation Technology Series No. 3</th>
<th>Application of Radiotracer Techniques for Interwell Studies</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAEA Radiation Technology Series No. 4</td>
<td>Guidelines for Development, Validation and Routine Control of Industrial Radiation Processes</td>
<td>10</td>
</tr>
<tr>
<td>IAEA Radiation Technology Series No. 5</td>
<td>Radiotracer Generators for Industrial Applications</td>
<td>11</td>
</tr>
</tbody>
</table>

**IAEA Radioisotopes and Radiopharmaceuticals Series**

<table>
<thead>
<tr>
<th>IAEA Radioisotopes and Radiopharmaceuticals Series No. 3</th>
<th>Cyclotron Produced Radionuclides: Guidance on Facility Design and Production of [18F]Fluorodeoxyglucose (FDG)</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAEA Radioisotopes and Radiopharmaceuticals Series No. 4</td>
<td>Cyclotron Produced Radionuclides: Operation and Maintenance of Gas and Liquid Targets</td>
<td>4</td>
</tr>
</tbody>
</table>

**IAEA Safety Standards Applications Series**

| IAEA Safety Standards Application Series No. 8 | Peer Review of the Radioactive Waste Management Activities of COVRA, Netherlands | 22 |

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Please note that this index does not detail all available safety standards. Only titles published in 2012 and 2013 and those forthcoming in 2013 and 2014 are shown. For a full list, please visit the safety standards web site: www-ns.iaea.org/standards or the IAEA books website: www.iaea.org/books or email sales.publications@iaea.org.
## General Safety Standards (applicable to all facilities and activities)

<table>
<thead>
<tr>
<th>IAEA Safety Standards Series No.</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSR Part 3</td>
<td>Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards</td>
<td>14</td>
</tr>
<tr>
<td>GS-R-3</td>
<td>The Management System for Facilities and Activities</td>
<td>17</td>
</tr>
<tr>
<td>GSG-2</td>
<td>Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency</td>
<td>22</td>
</tr>
<tr>
<td>GSG-3</td>
<td>The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste</td>
<td>24</td>
</tr>
<tr>
<td>GSG-4</td>
<td>Use of External Experts by the Regulatory Body</td>
<td>24</td>
</tr>
</tbody>
</table>

## Specific Safety Standards (applicable to specified facilities and activities)

### Nuclear Power Plants

<table>
<thead>
<tr>
<th>IAEA Safety Standards Series No.</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSR-2/1</td>
<td>Safety of Nuclear Power Plants: Design</td>
<td>17</td>
</tr>
<tr>
<td>SSR-2/2</td>
<td>Safety of Nuclear Power Plants: Commissioning and Operation</td>
<td>16</td>
</tr>
<tr>
<td>NS-G-2.11</td>
<td>A System for the Feedback of Experience from Events in Nuclear Installations</td>
<td>15</td>
</tr>
<tr>
<td>NS-G-2.14</td>
<td>Conduct of Operations at Nuclear Power Plants</td>
<td>15</td>
</tr>
<tr>
<td>SSG-2</td>
<td>Deterministic Safety Analysis for Nuclear Power Plants</td>
<td>15</td>
</tr>
<tr>
<td>SSG-15</td>
<td>Storage of Spent Nuclear Fuel</td>
<td>23</td>
</tr>
<tr>
<td>SSG-16</td>
<td>Establishing the Safety Infrastructure for a Nuclear Power Programme</td>
<td>12</td>
</tr>
<tr>
<td>SSG-21</td>
<td>Volcanic Hazards in Site Evaluation for Nuclear Installations</td>
<td>17</td>
</tr>
<tr>
<td>SSG-25</td>
<td>Periodic Safety Review for Nuclear Power Plants</td>
<td>16</td>
</tr>
<tr>
<td>SSG-28</td>
<td>Commissioning for Nuclear Power Plants</td>
<td>15</td>
</tr>
</tbody>
</table>

### Fuel Cycle Facilities

<table>
<thead>
<tr>
<th>IAEA Safety Standards Series No.</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSG-15</td>
<td>Storage of Spent Nuclear Fuel</td>
<td>23</td>
</tr>
<tr>
<td>SSG-21</td>
<td>Volcanic Hazards in Site Evaluation for Nuclear Installations</td>
<td>17</td>
</tr>
</tbody>
</table>

### Research Reactors

<table>
<thead>
<tr>
<th>IAEA Safety Standards Series No.</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSG-15</td>
<td>Storage of Spent Nuclear Fuel</td>
<td>23</td>
</tr>
<tr>
<td>SSG-20</td>
<td>Safety Assessment for Research Reactors and Preparation of the Safety Analysis Report</td>
<td>18</td>
</tr>
<tr>
<td>SSG-21</td>
<td>Volcanic Hazards in Site Evaluation for Nuclear Installations</td>
<td>17</td>
</tr>
<tr>
<td>SSG-22</td>
<td>Use of a Graded Approach in the Application of the Safety Requirements for Research Reactors</td>
<td>19</td>
</tr>
<tr>
<td>SSG-24</td>
<td>Safety in the Utilization and Modification of Research Reactors</td>
<td>18</td>
</tr>
</tbody>
</table>

### Radioactive Waste Disposal Facilities

<table>
<thead>
<tr>
<th>IAEA Safety Standards Series No.</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSR-5</td>
<td>Disposal of Radioactive Waste</td>
<td>22</td>
</tr>
<tr>
<td>SSG-23</td>
<td>The Safety Case and Safety Assessment for the Disposal of Radioactive Waste</td>
<td>23</td>
</tr>
</tbody>
</table>

### Application of Radiation Sources

<table>
<thead>
<tr>
<th>IAEA Safety Standards Series No.</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSG-11</td>
<td>Radiation Safety in Industrial Radiography</td>
<td>21</td>
</tr>
</tbody>
</table>
IAEA Safety Standards Series No. SSG-17 Control of Orphan Sources and Other Radioactive Material in the Metal Recycling and Production Industries 19
IAEA Safety Standards Series No. SSG-19 National Strategy for Regaining Control over Orphan Sources and Improving Control over Vulnerable Sources 19
IAEA Safety Standards Series No. SSG-27 Criticality Safety in the Handling of Fissile Material 19

Transport of Radioactive Material

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<table>
<thead>
<tr>
<th>Number of Titles</th>
<th>Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>€18.00</td>
</tr>
<tr>
<td>2</td>
<td>€28.00</td>
</tr>
<tr>
<td>3</td>
<td>€40.00</td>
</tr>
<tr>
<td>4</td>
<td>€50.00</td>
</tr>
<tr>
<td>5</td>
<td>€55.00</td>
</tr>
</tbody>
</table>

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IAEA TECDOC CD Series No. 1692 Water Chemistry and Clad Corrosion/Deposition Including Fuel Failures 33
IAEA TECDOC CD Series No. 1693 Hot Cell Post-irradiation Examination and Poolside Inspection of Nuclear Fuel 32
IAEA TECDOC Series No. 1639/Rev1 Assessment of Nuclear Energy Systems Based on a Closed Nuclear Fuel Cycle with Fast Reactors 26, 32
IAEA TECDOC Series No. 1671 Greater Agronomic Water Use Efficiency in Wheat and Rice Using Carbon Isotope Discrimination 6
IAEA TECDOC Series No. 1672 Modelling of Transport of Radioactive Substances in the Primary Circuit of Water Cooled Reactors 29
IAEA TECDOC Series No. 1673 Monitoring Isotopes in Rivers: Creation of the Global Network of Isotopes in Rivers (GNIR) 9
IAEA TECDOC Series No. 1674 Advances in High Temperature Gas Cooled Reactor Fuel Technology 28, 33
IAEA TECDOC Series No. 1675 Knowledge Management for Nuclear Research and Development Organizations 30
IAEA TECDOC Series No. 1676 Role of Nuclear Based Techniques in Development and Characterization of Materials for Hydrogen Storage and Fuel Cells 7
IAEA TECDOC Series No. 1677 Natural Circulation Phenomena and Modelling for Advanced Water Cooled Reactors 29
IAEA TECDOC Series No. 1679 Exemption from Regulatory Control of Goods Containing Small Amounts of Radioactive Material 39
IAEA TECDOC Series No. 1680 Spent Fuel Performance Assessment and Research: Final Report of a Coordinated Research Project (SPAR-II) 35
IAEA TECDOC Series No. 1681 Neutron Transmutation Doping of Silicon at Research Reactors 10
IAEA TECDOC Series No. 1682 Advances in Nuclear Power Process Heat Applications 27
IAEA TECDOC Series No. 1683 Quality Control for Expanded Tsetse Production, Sterilization and Field Application 6
IAEA TECDOC Series No. 1684 INPRO Collaborative Project: Proliferation Resistance: Acquisition/Diversion Pathway Analysis (PRADA) 43
IAEA TECDOC Series No. 1686 Experiences and Trends of Manufacturing Technology of Advanced Nuclear Fuels 34
IAEA TECDOC Series No. 1687 Fuel Modelling at Extended Burnup (FUMEX-II) 34
IAEA TECDOC Series No. 1688 Comparison of Heavy Water Reactor Thermalhydraulic Code Predictions with Small Break LOCA Experimental Data 28
IAEA TECDOC Series No. 1689 Design, Manufacturing and Irradiation Behaviour of Fast Reactor Fuel 34
IAEA TECDOC Series No. 1690 Review of Sealed Source Designs and Manufacturing Techniques Affecting Disused Source Management 36
IAEA TECDOC Series No. 1691 Status of Fast Reactor Research and Technology Development 30
IAEA TECDOC Series No. 1694 Evaluation of High Temperature Gas Cooled Reactor Performance: Benchmark Analysis Related to the PBMR-400, PBMM, GT-MHR, HTR-10 and the ASTRA Critical Facility 30
IAEA TECDOC Series No. 1695 Application of Isotope Techniques for Assessing Nutrient Dynamics in River Basins 9
IAEA TECDOC Series No. 1696 Challenges Related to the Use of Liquid Metal and Molten Salt Coolants in Advanced Reactors 28
IAEA TECDOC Series No. 1697 Improvement of Computer Codes Used for Fuel Behaviour Simulation (FUMEX-III) 34
IAEA TECDOC Series No. 1698 Performance Assessment of Passive Gaseous Provisions (PGAP) 29
IAEA TECDOC Series No. 1699 Dense Magnetized Plasmas 37
IAEA TECDOC Series No. 1700 BN-600 MOX Core Benchmark Analysis: Results from Phases 4 and 6 of a Coordinated Research Project on Updated Codes and Methods to Reduce the Calculation Uncertainties of the LMFR Reactivity Effects 33
IAEA TECDOC Series No. 1701 The Behaviour of Cementitious Materials in Long Term Storage and Disposal of Radioactive Waste — Results of a Coordinated Research Project 36
IAEA TECDOC Series No. 1702 Planning, Management and Organizational Aspects in Decommissioning of Nuclear Facilities 33
IAEA TECDOC Series No. 1703 Benchmark Analyses on the Natural Circulation Test Performed during the PHENIX End-of-life Experiments 25
IAEA TECDOC Series No. 1704 Pathways to Energy from Inertial Fusion: An Integrated Approach 37
IAEA TECDOC Series No. 1706 Instrumentation for Digital Nuclear Spectroscopy 7
IAEA TECDOC Series No. 1709 Fuel Behaviour and Modelling under Severe Transient and Loss of Coolant Accident (LOCA) Conditions 34
IAEA TECDOC Series No. 1712 Management of NORM Residues 35
<table>
<thead>
<tr>
<th>Series</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>INSAG Series</td>
<td>INSAG Series No. 26 Licensing the First Nuclear Power Plant</td>
<td>13, 16</td>
</tr>
<tr>
<td>Operating Experience</td>
<td>Operating Experience Operating Experience with Nuclear Power Stations in Member States in 2011</td>
<td>27</td>
</tr>
<tr>
<td>Proceedings Series</td>
<td>Research Reactors: Safe Management and Effective Utilization</td>
<td>7, 18</td>
</tr>
<tr>
<td></td>
<td>Justification of Medical Exposure in Diagnostic Imaging</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Isotopes in Hydrology, Marine Ecosystems and Climate Change Studies</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Fast Reactors and Related Fuel Cycles: Challenges and Opportunities (FR09)</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Human Resource Development for Introducing and Expanding Nuclear Power Programmes</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Fast Reactors and Related Fuel Cycles: Challenges and Opportunities (FR09)</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Management and Storage of Research Reactor Spent Nuclear Fuel</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Remediation of Land Affected by Radioactive Residues</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Preparing for Future Verification Challenges</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Isotopes in Hydrology, Marine Ecosystems and Climate Change Studies</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Remediation of Land Affected by Radioactive Residues</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Sources and Measurements of Radon and Radon Progeny Applied to Climate and Air Quality Studies</td>
<td>41</td>
</tr>
<tr>
<td>Reference Data Series</td>
<td>Reference Data Series No. 2 Nuclear Power Reactors in the World</td>
<td>25</td>
</tr>
<tr>
<td>Safety Reports Series</td>
<td>Monitoring for Compliance with Exemption and Clearance Levels</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Management System Standards: Comparison between IAEA GS-R-3 and ISO 9001:2008</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Management System Standards: Comparison between IAEA GS-R-3 and ASME NQA-1-2008 and NQA-1a-2009 Addenda</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Radiation Protection in Paediatric Radiology</td>
<td>3, 21</td>
</tr>
<tr>
<td></td>
<td>Monitoring for Compliance with Remediation Criteria for Sites</td>
<td>13, 22</td>
</tr>
<tr>
<td></td>
<td>Low Level Event and Near Miss Process for Nuclear Power Plants: Best Practices</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Safety Culture in Pre-operational Phases of Nuclear Power Plant Projects</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Implementation of a Management System for Operating Organizations of Research Reactors</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Radiation Protection and NORM Residue Management in the Titanium Dioxide and Related Industries</td>
<td>21, 23</td>
</tr>
<tr>
<td></td>
<td>Safety Assessment for Decommissioning</td>
<td>23, 33</td>
</tr>
<tr>
<td>Safety Reports Series No. 78</td>
<td>Radiation Protection and Management of NORM Residues in the Phosphate Industry</td>
<td>21</td>
</tr>
<tr>
<td>Safety Reports Series No. 78</td>
<td>Radiation Protection and Management of NORM Residues in the Phosphate Industry</td>
<td>36</td>
</tr>
</tbody>
</table>

**Technical Reports Series**

<p>| Technical Reports Series No. 473 | Nuclear Data for the Production of Therapeutic Radionuclides | 5, 8 |
| Technical Reports Series No. 474 | Measurement and Calculation of Radon Releases from NORM Residues | 7 |
| Technical Reports Series No. 475 | Guidelines for Remediation Strategies to Reduce the Radiological Consequences of Environmental Contamination | 40 |</p>
<table>
<thead>
<tr>
<th>Series &amp; No.</th>
<th>Title</th>
<th>Language</th>
<th>ISBN</th>
<th>IAEA Reference</th>
<th>Published</th>
<th>Price (Euro)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAEA TECDOC Series No. 1674</td>
<td>Advances in High Temperature Gas Cooled Reactor Fuel Technology</td>
<td>E</td>
<td>978-92-0-125310-1</td>
<td>IAEA-TECDOC-1674</td>
<td>2012</td>
<td>18.00</td>
</tr>
<tr>
<td>IAEA TECDOC Series No. 1682</td>
<td>Advances in Nuclear Power Process Heat Applications</td>
<td>E</td>
<td>978-92-0-130210-6</td>
<td>IAEA-TECDOC-1682</td>
<td>2012</td>
<td>18.00</td>
</tr>
<tr>
<td>Proceedings CD Series</td>
<td>Advances in Radiation Oncology Proceedings of an International Conference held in Vienna, Austria, 27–29 April 2009</td>
<td>E</td>
<td>978-92-0-161710-1</td>
<td>STI/PUB/1485</td>
<td>2011</td>
<td>18.00</td>
</tr>
<tr>
<td>IAEA TECDOC Series No. 1670</td>
<td>Análisis Probabilista de Seguridad de Tratamientos de Radioterapia con Acelerador Lineal</td>
<td>S</td>
<td>978-92-0-322610-3</td>
<td>IAEA-TECDOC-1670</td>
<td>2012</td>
<td>18.00</td>
</tr>
<tr>
<td>IAEA TECDOC Series No. 1685</td>
<td>Aplicación del Método de Análisis de Matriz de Riesgo a la Radioterapia</td>
<td>S</td>
<td>978-92-0-332510-3</td>
<td>IAEA-TECDOC-1685</td>
<td>2013</td>
<td>18.00</td>
</tr>
<tr>
<td>Safety Reports Series No. 65</td>
<td>Application of Configuration Management in Nuclear Power Plants</td>
<td>E</td>
<td>978-92-0-106710-4</td>
<td>STI/PUB/1461</td>
<td>2010</td>
<td>42.00</td>
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