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BRAZILIAN URANIUM
EXPLORATION PROGRAM

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ABSTRACT

Due to the growing demand of electric power to support Brazil's development as well as the constant price raises of fossil fuels and the scarcity of additional hydroelectric resources, the use of nuclear energy will be indispensable.

The nuclear fuel cycle for the production of energy starts with the exploration for uranium ores.

The work performed in this field led to the discovery of several ore deposits in the country such as: FIGUEIRA/PARANÁ (Middle Permian sandstones of the Paraná Basin), POÇOS DE CALDAS/MINAS GERAIS (alkaline rock of Upper Cretaceous age)-which will be in operation late in 1981 with a nominal capacity of 500 tpy of U3O8-, QUADRILÁTERO FERRÍFERO/MINAS GERAIS (metaglomerates in Precambrian domain), LAGOA REAL/BAHIA (metasomatites/linear albitites in Precambrian rocks), AMORINÓPOLIS/GOIÁS (Eonion sandstones of the Paraná Basin), CAMPOS BELOS - RIO PRETO /GOIÁS (vein unconformity type in Precambrian rocks), ESPINHARAS/PARAI BA (metasomatites in Precambrian domain), and ITATAIA/CEARÁ (metasomatites in Precambrian domain also).

Brazil's total uranium reserves amount presently to 236,300 tonnes of U3O8 placing the country, probably, as the 6th largest reserve in the western world. This tonnage is equivalent to 1,645 Mtep and enabling the supply of 40 Angra-2 type (1245 MWe) nuclear power plants over its 30 years lifetime.
1. INTRODUCTION

The sudden raise in petroleum prices in 1973 had a significant impact on the Brazilian economy. In 1980 almost 48% of the net income from the country's export were absorbed by the imported oil. Consequently, problems with the balance of payments occurred, inflation rose and GNP index fell.

The perspectives of soaring prices of the fossil fuels and, in the long range, the physical exhaustion of the hydroelectric energy sources, compelled the Brazilian government to look for a diversification in energy sources within the country. Thus, combining energy preservation policies, enlarged emphasis on the exploration and exploitation of the domestic oil and coal reserves, the government defined, in 1974, the Brazilian Nuclear Program both to secure and provide the country with the electric power required for its development, as well as the technology of the entire nuclear fuel cycle (FIG.1). A Cooperation Agreement with Western Germany for the transfer of nuclear technology was signed in 1975 as part of this Program.

Several organizations take part in this program each with its own attribution (FIG.2).

The present status of the Brazilian Nuclear Program is as follows:

Uranium Exploration - is being carried out and right now the uranium reserves amount to 236,300 t of U3O8.

Uranium Mining - the first Brazilian uranium mine and mill is in its final construction phase at Poços de Caldas and will be brought into operation in the last quarter of 1981. The mill's nominal capacity is 500 t/year of U3O8. Other deposits are scheduled to come into production in '86, '87 and '88.

Conversion Plant - it is, presently, in the engineering stage.
Enrichment Plant - the jet-nozzle process demonstration plant is under construction and is scheduled to be operating at the end of 1983 (first cascade - 24 stages) and reaching its final capacity of 80 tonnes of SWU in 1986. The second one is scheduled for 1988, with a capacity of 300 tonnes SWU.

Fuel Element Fabrication Plant - the first stage (assembly fuel element) is already built; the second one is scheduled for 1984 and the third one for 1985.

Heavy Components Fabrication Plant - it started operations in 1980 and is now producing heavy components (pressure vessel, pressurizers, steam generators, etc) for NPP3 and NPP4 and for Atucha 2 (Argentina).

Nuclear Power Plants - the first brazilian PWR - WESTINGHOUSE NPP (628 MWe) will be brought into production by the end of this year. The second one PWR-KWU (1245 MWe) is in the initial construction stage of the pressure vessel building while the foundations for the third one are being laid out. In January the geological studies to select the sites of NPP4 and NPP5 (FIG.3) were started.

Total investments for the Brazilian Nuclear Program, until 1995, are estimated at US$ 17,5 billion, of which 13,5 billion for the nuclear power stations and 4,0 billion for the rest of nuclear fuel cycle.

2. GENERAL INFORMATION ON BRAZIL'S URANIUM EXPLORATION PROGRAM

Uranium exploration has been carried out in Brazil since 1952 with particular emphasis during the last six years.

An initial objective was the evaluation of the uranium resources associated with zirconium ores (caldasite) of the Poços de Caldas Plateau.
Until 1970 uranium exploration was mostly confined to the Paleozoic and Mesozoic sedimentary basins. However it should be noted that some reconnaissance was carried out in the Precambrian domains as well, and this led to the selection of large areas for aerogeophysical surveys.

From 1974 to 1978 there was a significant increase in airborne gamma-ray surveys over the Precambrian basement which amounted to 3,000,000 km² of a total area of 4,300,000 km² of Precambrian rock units.

The promising results of those surveys led to shift in emphasis from the sedimentary basins to the Precambrian domains and this shift resulted in areas in variety of geological environments which were delimited for detailed studies, including the new deposits located at Itataia and Lagoa Real in northeastern part of the country.

In the figures 4 and 5 it can be seen the development of uranium exploration work during the last years.

The rapid progress made after 1975 (when known reserves amounted to 11,040 t of U₃O₈) in the identification and exploration of uraniumiferous districts can be attributed to the growth of funds and the following of a rational sequence of stages which include:

a) Regional Geology. The selection and verification of potentially favourable areas following integrated studies based on all available information. Geological thinking is a fundamental aspect of this stage.

b) Prospection and Exploration. This stage follows as a consequence of the preliminary studies. Specific programs are established in favourable areas based on the use of traditional prospection methods. Preliminary feasibility studies are also carried out during this stage, including
ore reserves estimation and economic evaluation.

With respect to the philosophy of evaluation, it should be noted that all prospects are evaluated irrespective of the degree of mineralization but taking into account their potential so that expenditures are not in excess to what may be found.

The estimation of reserves is based not only on conventional techniques (blocks, isolines, parallel sections, etc.), but also on statistical and geostatistical methods such as Kriging and Cokriging using available computer programs developed by NUCLEBRAS. The use of these various techniques both consecutively and simultaneously, permits a high degree of precision in the evaluation (FIG.6) (Marques et alii, 1980).

The concept of "Measured Reserves" and "Indicated Reserves" (Reasonably Assured), and "Inferred Reserves" (Estimated Additional) is based on a series of criteria. These include the estimation methods used, the regularity of the sampling grid, the grid spacing, the percentage of core recovery, the relationship between the number of chemical and radiometric data from the mineralized horizons, the degree of co-relation of the regression line between radioactivity and chemical grade, and, finally, the relative error with respect to the most probable value of U3O8 tonnage at the 95% confidence level.

It should be emphasized that the maximum value of the errors considered are compatible with the class of reserves reported, and that, for Measured Reserves, one of the techniques always used is geostatistics. Also for Measured Reserves, the relationship used between data from chemical and radiometric analysis is much greater than that internationally adopted.

These computations are greatly facilitated by delayed neutron analysis for U3O8 which permits a large number of samples to be processed quickly.
Reported reserves are defined as those economically viable on the basis of an international value of US$ 40.00/lb U3O8.

The work done up to now led to the evaluation of reserves as shown in figures 7 and 8.

3. MAJOR BRAZILIAN URANIUM DEPOSITS

The major Brazilian uranium deposits (FIG. 9) are in different stages of evaluation and development. The large deposits at Poços de Caldas, Figueira, Itataia, and part of Lagoa Real are scheduled for exploitation.

The deposits at Espinharas, Amacrinopolis and part of Lagoa Real are being developed and those ones at Rio Preto, Campos Belos and Quadrilátero Ferrífero are still in an early stage of investigation.

This paper describes only the most important deposits: Figueira, Poços de Caldas (Osamu Utsumi Mine), Lagoa Real and Itataia.

3.1 The Figueira Deposit

The Figueira uranium deposit is located in the north-central part of the State of Paraná close to the village of the same name, 300 km northwest of Curitiba, in a region of undulating relief.

This deposit was discovered following a systematic survey of the coal basins of southern and southeastern Brazil in 1969. The detailed work began in 1969, and environments favourable for uranium were determined from the interpretation of drill hole cores. By 1978, the Reasonably Assured reserves amounted to 7,000 tonnes U3O8 and it was decided to develop the property to an industrial level and underground workings of an exploratory nature commenced.
The deposit is located in the Middle Permian sediments (Rio Sonito Formation) near the eastern margin of the Parararás basin. In the Figueira area, the sediments vary in age from the Carboniferous to the Upper Permian and dip gently (about 19°) to the north-west. The entire sedimentary package is cut by basic dykes of Cretaceous age (FIG. 10).

The Rio Sonito Formation varies in thickness from 120 to 130 m and was divided into three stratigraphic intervals based on electric and lithological logs (Saad, 1974). The basal interval (15 to 30 m) is composed of very fine grained to conglomeratic sandstones which are light to dark grey in colour with intercalations of arkoses, siltstones, coal, dark shales and occasional beds of grey limestones. These sediments frequently possess a calcareous cement in addition to pyrite. This interval has been interpreted to have been deposited in fluvial channels, on flood plains and in swamps. The middle interval (85 m), consists of grey, green or yellow siltstones intercalated with variegated marls and light to medium grey limestones. White to red sandstones, characterized by parallel lamination are also found in this interval. These sediments were probably deposited on a marine shelf below wave base. The upper interval (20 m) consists of very fine grained laminated sandstones with intercalations of siltstones. These sediments were probably deposited on the shallow part of a shelf or close to the shoreline (FIG. 11).

The uranium of the Figueira deposit is thought to have come from reworked sediments of the Itararé Formation (Permo-Carboniferous) which contains boulders of the crystalline basement with anomalous concentrations of this element. Additional contributions may have come from clasts derived from uranium-rich rhyolite dykes of Cambrian age.

An important factor in the genesis of the Figueira mineralization was the local development of several types of
depositional environments in response to regional tectonic arching. These environments had distinct paleogeographic limits, sediment-types and mineralization characteristics.

According to Saad (1974), the mineralization which occurred in the basal sediments of the Rio Bonito Formation, 100 meters below the surface, was the result of both syngenetic and epigenetic processes. The syngenetic mineralization occurred in swamps containing fine grained sediments rich in organic material while the epigenetic mineralization developed in the fluvial-deltaic environments in which the sedimentation was mainly of a sandy character with intercalations of argillaceous and carbonaceous material.

The formation of the epigenetic uranium followed a sequence of phases involving transport and deposition which may have occurred both before and after diagenesis of the host rocks. Groundwater of a slightly alkaline nature may have remobilized the U⁴⁺ uranium transporting it in the U⁶⁺ form (oxidized state) to reducing environments where it was redeposited in geochemical cells. It is probable that this process remained active throughout the Paleozoic deposition.

The main ore body is lenticular in shape and accompanies a north-south trending paleochannel. The body is about 3000 m long and 600 m wide, in average.

In the mineralized unit, uranium is associated with sandstones, siltstones, clays, and carbonaceous sediments including coal. Uranium occurs as uraninite in the interstitial spaces of the calcareous cemented sandstones. In the siltstones, carbonaceous clays and coals, the uranium mineralization occurs in the form of organo-mineral complexes of phosphate, barium and uranium, mineralogically classified as uranocircite. In the uranium-rich zones, the concentrations of U₃O₈ vary from about 0.2 to 0.5% and average 1.5 to 3.5 m in thickness. The principal accessory minerals
include pyrite, jordsite, galena and chalcopyrite along with sulphides or arsenic and thorium-rich minerals.

Present reserves are 8,000 tonnes U3O8 from which 7,000 tonnes are Reasonably Assured, but exploration is being carried out on surrounding areas where similar deposits are expected to occur (Harmonia and Ibaiti prospects).

3.2 The Alkaline Intrusive Rocks of Brazil

About 70 alkaline intrusive bodies are known in Brazil. These vary considerably with respect to their age, size and geographical distribution. In general terms, the majority of these fall into four geographical areas and may have distinct petrographical, chemical and chronological characteristics although there may be some overlap of these as is the case of the large alkaline complex of Poços de Caldas. The four geographical areas include the Amazon region, southern Bahia, around the periphery of the Paraná Basin, and lastly, a northeast-southwest trending belt of intrusives in the states of Rio de Janeiro and São Paulo.

The groups of intrusives which are best known are those which occur in the southeastern part of the country, specifically, those around the periphery of the Paraná Basin and those of the northeast-southwest trending zone of the states of Rio de Janeiro and São Paulo. The intrusives lie in two orogenic belts known as the Brasília and Ribeira belts.

The alkaline intrusives belonging to the Rio de Janeiro - São Paulo group are generally felsic in composition, homogeneous and only slightly tectonized. The Th/U ratios are high but the uranium mineralization is weak.

By comparison, the alkaline intrusives which follow the
periphery of the Paraná Basin are very variable with respect to their lithological and chemical character. They vary from ultrabasic to hyperalkaline and frequently consist of large carbonatite masses rich in phosphates.

The second group appear to offer the best prospectives for uranium. Indeed, appreciable resources of uranium-rich phosphates are known at Araxá and at Catalão, where the average uranium content is about 150 ppm. Uranium also occurs in such stable resistate mineral such as pyrochlore.

The majority of the Brazilian alkaline bodies occur as intrusives in metamorphic rocks and are structurally controlled by large regional fault systems which were re-activated at various times in the geological past.

Petrochemical studies have shown that there is a dominance of the miaskitic type of alkaline intrusive which are considered to be less favourable for significant uranium mineralization as compared to the agpaitic variety. The agpaitic intrusives tend to be small and are generally associated with late stage magmatic activity. However, the alkaline complex at Poços de Caldas may be an exception, subject to further study.

With the exception of the Poços de Caldas complex, the extraction of uranium from the Brazilian alkaline rocks is not considered to be economical, although a potential of 60,000 and 30,000 tonnes of U3O8 are estimated at Araxá and at Catalão respectively (Loureiro, 1980).

At Catalão an industrial process has been mounted to produce apatite concentrates in which gorceixite is discarded as a waste product. Studies carried out by NUCLEBRAS found that the uranium concentration in the gorceixite was higher than in the apatite concentrates, but unfortunately, the uranium can not be extracted economically at present.
The complex is situated between the Serra da Mantiqueira to the east and the Paraná Basin to the west. It is roughly circular in shape and some 30 km in diameter. The complex was intruded into Precambrian biotite gneisses with anatexites developed locally (FIG. 12). The intrusion caused the formation of radial and sub-circular faults with concomitant metasomatism around the periphery of the complex. This phenomena was accentuated in the vicinity of the eastern and southeastern contacts where fenitization was most prevalent.

Within the main structure there are some 14 circular structures which represent plug-like intrusions in addition to the Rio Pardo Stock which lies outside the complex. All these structures are well seen on LANDSAT and side scanning radar images.

The complex is characterized by a wide variety of rock types as well as pronounced mineralogical and textural diversification of each rock type from very coarse grained to very fine grained. This has given rise to the hypothesis of varied emissions of magma accompanied by differentiation phenomena. The most common rock types belong to the family of the nepheline syenites and in order of decreasing importance these include tinguaiteis, phonolites, nepheline syenites, foyaites, lujaurites and chibinites. The complex has a strong agpaitic tendency (Forman, 1966). Besides the syenites are found rocks of volcanic ejection origin such as tuffs, agglomerates, ashes and breccias. In the central part of the complex, the rocks have been highly altered by intense potassic metasomatism. The best outcrops are found in the northern region and these are generally of the lujaurite, chibinite and tinguaite types. In the northeastern part of the complex occur Mesozoic sediments of the Paraná Basin (Ellert, 1959).
Within the complex there are two principal fault systems, the strikes of which are N60°W and N40°E. The first of these is related to the major regional trend since this is found both within the complex as well as outside it. These faults were reactivated during uplift. The second fault system is genetically related to the formation of the collapse caldera. Two other fault systems which strike N-S and E-W respectively, are local phenomena and are probably contemporaneous with the subsidence of the caldera. In the Campo do Cercado deposit, known today as the Osamu Utsumi Mine, there is a local fault system trending NNE.

The ring dykes following the periphery of the complex were intruded along ring faults, and it is likely that these formed after the initial stage of subsidence.

On the basis of whole rock K/Ar determinations, Amaral et alii (1967), dated the intrusions at between 80 and 62 m.y. A similar age of 75 m.y. was obtained for the leucocratic foyaites of the Rio Pardo Stock showing these to be coeval with the main intrusions. However, it should be noted that Pb/α determinations on zircon from caldasite gave somewhat older ages of 98 m.y. (Dutra, 1966).

The evolutionary stages of the alkaline complex of Poços de Caldas are described briefly with reference to FIG.13 and 14. In outline the sequence is similar to that described by Ellert (1952), Biondi (1976) and Tilsley (1976), although it may differ in detail. When the Smith and Bailey (1968) Resurgent Cauldron Model is applied to Poços de Caldas, the evolutionary stages are as follows (Santos,1978):

1. The uplift of the crystalline basement and overlying Phanerozoic sediments of the Paraná Basin caused the development of the first echelon faults.

2. This was followed by a long period of volcanic activity which was sometimes expressed as lava flows and
sometimes of explosive character which resulted in the formation of tuffs and volcanic breccias.

3. The partial withdrawal of the magma chamber which caused the initial uplift provoked subsidence of the central parts of the complex forming a collapse caldera. This was accompanied by brecciation, milonitization and intense tectonism. The evidence for this event is manifested further in the large block of sedimentary rocks which dip towards the centre of the structure.

4. A second (resurgent phase) of uplift accompanied by intrusions of tinguaites and foyaïtes along the radial and circular fractures formed during the first stage. The foyaïte intrusions are genetically related to this second phase of uplift as well as to the uranium mineralization.

5. Major ring-fracture volcanism.

6. Intrusions of lujaurite, chibinite and foyaïte accompanied by hydrothermal as well as late or post magmatic activity including tufficitic brecciation and terminal hot-spring activity. This stage was characterized by intense erosion.

The Osamu Utsumi Mine is situated near the southern margin of the major secondary crater of the Poços de Caldas Plateau. It underlies an area of 20 km², and has been divided into three ore bodies which have been designated as the "A", "B" and "E" ore bodies respectively (FIG. 15).

The "A" and "E" ore bodies constitute an homogeneous lithological entity and probably formed part of a volcanic plug composed of phonolite and tinguaita. The "B" ore body is situated in rocks which constituted the external part of an volcanic cone composed mainly of pyroclastics. The presence of three distinct types of mineralization in a restricted area can be explained by the fact that there may occur, in large volcanic regions, both, low and high
energy environments resulting in mineral deposits which formed under different geological conditions. Genetically speaking, hydrothermal activity appears to have been the most important process responsible for the mineralization at Poços de Caldas. Fluidization phenomena (Biondi, 1976 and Tilsley, 1976) and secondary enrichment occurred on a smaller scale. The secondary uranium mineralization has been attributed to both hydrothermal and meteoric processes. Hydrothermal activity caused a strong argillization of the rocks resulting in the formation of kaolinite and halloysite. Hydrothermal activity also caused sericitization and the formation of fluorite and pyrite. Some uranium was also liberated from the uranium-rich caldasites by leaching. Surficial weathering and the leaching of uranium by downward percolating waters is considered to be a function of porosity, permeability and the degree of rock fracture. It was once thought that the mineralization was controlled and conditioned by vertical magmatic intrusions. Today it is known that the sub-horizontal mineralized bodies are related to alteration phenomena, lithological controls, and the secondary enrichment in certain specified facies.

The primary uranium mineralization is found in bodies of breccia attributed to tufficitic brecciation ("A" ore body) and as the result of hydrothermal activity related to intrusive phenomena ("B" ore body). The secondary uranium mineralization occurs in all three ore bodies, but it is best developed in the "E" ore body where the formation of the uranium has been attributed to hydrothermal processes.

The uranium ore is composed of black oxides of uranium and their oxidation products, and it is sometimes accompanied by coffinite, molybdenum-bearing minerals, zircon, fluorite and pyrite. Galena and sphalerite occur rarely (Gorsky and Gorsky, 1974).

The characteristics of the ore bodies are as follows:
The "A" ore body is about 900 m long and 530 m wide. Mineralization is known to a depth of 250 m. The body consists of a compact microgranular rock belonging to the family of the phonolitic lavas and is cut by tabular breccia bodies of sub-vertical attitude in which the uranium-molybdenum mineralization is found. In the "A" ore body, the primary mineralization is found in the tufficitic breccias where it occurs as pitchblende associated with pyrite, fluorite, jordisite and ilsemanite.

The mineralization has been attributed in the percolation of fluids and volatiles along the breccia pipe in which both fluidization and hydrothermal processes may have been active.

The epigenetic mineralization is composed of neofomed pitchblende and para-pitchblende which originated from the leaching of the tufficitic breccias.

Three tectonic systems have been identified within the "A" body. The most significant of these is related to the regional tectonic trend and these strike N60°W and dip 80°NE. The tufficitic breccias are associated with this system. Subsequent faulting with strike N40°E resulted in the cutting and partial dislocation of the ore body. Finally, the breccias were cut by a fault system striking N10°E to N25°E which was particularly prevalent in the central zone of the ore body, provoking a series of step-like structures.

The "B" ore body is 1,240 m in length and 440 m wide. Mineralization is known to a depth of 370 m. It is situated in an accumulation of pyroclastic material in a depression. However, the base of these is limited by the upper surface of a foyaite intrusion which post-dated the explosive volcanism. The principal rock types include phonolite, porphyritic phonolite, pseudoleucite-rich
phonolite, phonolitic tuffs, tufficitic breccias and intrusive foyaite, but due to intense tectonism, the tuffs, ashes and lavas found in vertical section have little continuity. The rocks are frequently cut by ultrabasic dykes and breccia pipes.

Three preferred directions of faulting have been recognized. The first system strikes NE-SW and served as a conduit for deep-seated mineralization. The second system strikes NW-SE and is genetically related to the enrichment of the intermediate parts of the ore body. The third system strikes N-S and is genetically related to the formation of fault breccias which may or may not be mineralized. Intense tectonism caused the dislocation of small blocks which at times conceals the sub-horizontal attitude of the pyroclastics. The foyaite intrusion at the base of the ore body is likewise tectonized, but not mineralized.

The mineralization of the "B" ore body is composed of black oxides of uranium associated with fluorite, pyrite and molybdenum bearing minerals. In the upper part, it shows epigenetic characteristics, being sub-horizontal and similar to that of the "A" and "E" ore bodies. In the lower part of the ore body, the mineralization is related to structural traps formed between down thrown blocks. This resulted in the formation of "amas" or mineralized pockets in the depressions which have been enriched by the lateral migration of hydrothermal solutions. The lower part of the body is limited in depth by the upper surface of the foyaite intrusion.

The "E" ore body is 1,100 m in length and 500 m wide. Mineralization is known to a depth of 140 m. The "E" ore body, like the "A" ore body, is situated in a plug-like intrusion which constituted the interior of a volcanic cone. The rocks consist of a light grey phonolite of micro- to aphanitic texture. The "A" ore body is thought
to be faulted against the "B" ore body which lies to the southeast.

All of the uranium mineralization is epigenetic and genetically related to the superimposition of metasomatic, meteoric and tectonic factors which controlled the nearly vertical migration of the hydrolysisation and the oxidation front.

In the "E" ore body, the distribution of the secondary uranium mineralization has been influenced by factors controlling the weathering front (degree of rock alteration, porosity, permeability, tectonism, etc.). In the upper part of the ore body, the mineralization occurs as small concentrations of low grade ore formed in an oxidizing environment in which the uranium was fixed by adsorption to clays and iron oxides and hydroxides. Uranium mineralization also occurred along the entire extension of the hydrolysisation and the oxidation fronts in the form of stains of black powdery uranium oxides. Here the largest concentrations are found adjacent to the faults where the front may follow the fault downdip. Lastly, the uranium mineralization may be related to tectonism. Here it may consist of massive or powdery pitchblende along with pyrite and some zircon. Modules of massive pitchblende formed in the fractures are associated with white clay. In the fault zones, there are concentrations which are known locally as "vaca leiteira" because they resemble the patches of dutch milk cows. These concentrations consist of pitchblende associated with neoformed pyrite and clay.

The ore reserves of Osamu Utsumi Mine are as follows:

<table>
<thead>
<tr>
<th>OXIDE</th>
<th>REASONABLY ASSURED (t)</th>
<th>ESTIMATED ADDITIONAL (t)</th>
<th>AVERAGE GRADE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U3O8</td>
<td>17,200</td>
<td>4,600</td>
<td>0,0847</td>
</tr>
<tr>
<td>K2O3</td>
<td>NA</td>
<td>25,000</td>
<td>0,11</td>
</tr>
</tbody>
</table>

NA - NOT ANNOUNCED
The Osamu Utsumi Mine will come into production in the last quarter of 1981 with a nominal capacity of 500 t U₃O₈/year (FIG. 16).

The main characteristics of the Poços de Caldas Mineral Industrial Complex are:

MINE

- STRIPPING .................. 85 million of m³ in the first 12 years
- AREA OF PIT ................ 500,000 m²
- DIAMETER OF PIT .......... 1,000 m
- RESERVES OF U₃O₈ TO EXTRACT .... 21,127 tonnes
- STORAGE CAPACITY .......... 300,000 tonnes of ore
- AREA FOR ORE STORAGE ...... 108,000 m²
- MINE PRODUCTION .......... 2,500 tonnes of ore/day

PLANT

- AREA OF PLATFORM .......... 340,000 m²
- AREA OF CONSTRUCTION .... 30,000 m²
- EQUIPMENTS ................. 1,800
- PANELS OF CONTROL INSTRUMENTS .... 400
- PIPE LINES .................. 3,000 m
- NOMINAL ORE CAPACITY .... 2,500 tonnes/day
- BASIC SUPPLIES (CHEMICAL REAGENTS) .... 25
- CONSUMPTION OF SULPHURIC ACID ... 390 tonnes/day
- CONSUMPTION OF LIMESTONE ........ 360 tonnes/day
- CONSUMPTION OF DEAD LIME ........ 88 tonnes/day
- CONSUMPTION OF PYHOLUSITE .... 55 tonnes/day

UTILITIES AND INDUSTRIAL FACILITIES

- INSTALLATIONS PROVIDING WATER, COMPRESSED AIR AND STEAM.
- SULPHURIC ACID PLANT UTILIZING NATIVE SULPHUR WITH A NOMINAL CAPACITY OF 360 TONNES OF ACID PER DAY.

SUPPORTING INSTALLATIONS

- LABORATORIES EQUIPED TO CARRY OUT CHEMICAL ANALYSIS, PHYSICAL ANALYSIS, PHYSICAL-CHEMICAL ANALYSIS FOR QUALITY CONTROL OF THE PRODUCTS AS WELL AS ENVIRONMENTAL AND RADIOLOGICAL CONTROL.
3.4 The Lagoa Real Uranium District

The Lagoa Real District is located in the hilly country of the southcentral part of the State of Bahia, some 20 km northeast of the town of Caetité.

The Lagoa Real District was discovered following the execution of several regional aerogeophysical surveys between 1976 and 1977, which led to the identification of 19 mineralized bodies. A more detailed airborne gama-spectrometrical survey led to the discovery of a further 44 important anomalies now being investigated.

The Caetité massif is located in the southern part of the São Francisco Craton of Bahia. It is about 80 km long and varies in width from 30 to 50 km. It consists of Archaean microcline gneisses along with granites, granodiorites, syenites and amphibolites. To the south, east and north there lie large areas of low relief which are underlain principally by gneisses and green schists of Archaean or Lower Proterozoic age. Along its western margin, the massif is frequently faulted against the metasediments and metavolcanics of the Espinhaço Super Group. The region may have been subjected to as many as three tectonic cycles during which the rocks were rejuvenated. These include the Guriense (3,000 m.y.), Trans-Amazonian (1,800-2,100 m.y.) and the Espinhaço/Brazilian (1,800-500 m.y.) cycles of which the last named was the most significant in terms of the uranium mineralization at Lagoa Real (Stein et alii, 1980).

The uranium mineralization occurs as "linear albitites" (Beus, In: Smirnov 1976) which are characterized by the
presence of sodic plagioclase, aegerine-augite and andradite. The country rocks are invariably microcline orthogneisses. The foliation of these gneisses is essentially parallel to the regional trend, which within the massif inscribes an arc. The fractures which also follow the strike are often cataclastized and their dip directions, as well as that of the foliation, are helicoidal from south to north. The mineralized bodies of metasomatic albitites surrounded by microcline gneiss are fusiform and likewise accompany the regional structural trends (FIG. 17). The length of these varies from 20 to 100 times the width, and the high grade mineralization is known to occur to a depth of 350m (FIG. 17).

The uranium mineralization has been attributed to sodium metasomatism during the Brazilian Cycle which is supported by absolute age dating (U/Pb) of the uraninite at 820 m.y. (Cooper, 1979). Solutions rich in sodium chloride and methane (found in fluid inclusions) ascended pre-existing fracture planes and zones of weakness within the microcline gneisses causing sodium metasomatism and the formation of the albite-pyroxene-andradite-rocks. The uranium in the microcline gneisses was likewise mobilized and concentrated as fine disseminations in the mafic bands of sodic pyroxene.

The principal uranium mineral is uraninite. Pitchblende is rare, but its occurrence is similar to that of the uraninite. B-Uranophane can be observed on fracture planes at the surface. The grades of U3O8 are quite high and may reach 3.50% in exceptional cases. The average grade of the mineralized zone is about 0.2 to 0.3% U3O8. The concentrations of thorium are low (<100 ppm). Reasonably Assured Reserves are presently 18,000 tonnes and the Estimated Additional for the district exceeds 30,000 tonnes U3O8.

Similar deposits and metallogenetic models have been described by Kazanski and Laverov (1977) in the U.S.S.R.
Elsewhere in the southern part of the Espinhaço Province, four uraniferous areas have been discovered recently. These have been called the Nova Era, São Sebastião do Maranhão, Francisco Sã and Monte Azul areas. These are presently being studied in detail.

3.5 The Central Ceará Uranium-Phosphate District

The first anomalies in the Central Ceará Region were discovered during the course of a carbone radiometric survey in 1975.

Additional anomalies have been found in 1978 after a 500m flight line-spacing airborne gamaspectrometric survey carried out over 38,000 km².

The Central Ceará U-P District lies in two tectonic units known as the Jaguaribean Fold Belt, and the Santa Quitéria Massif. This fold belt is bordered on the northeast and southwest by the Santa Quitéria Massif, the limits of which are, in part, marked by two large transcurrent faults known as the Groaira and Itatira faults respectively (FIG. 18).

The Jaguaribean Fold Belt consists of highly folded meta-sediments which overlie the granitic basement. These sediments include carbonates, arkoses and occasional beds of marl which have been metamorphosed to the grade of the amphibolite facies. The rocks are attributed to the Caicó Group (Upper Proterozoic). The folding within the belt has been attributed to differential movement between the stable blocks of the Santa Quitéria Massif.

The primitive rocks of the Santa Quitéria Massif consisted of sedimentary, volcanic and possibly basic rocks. These have been subjected to a high degree of sialization and have been transformed almost completely by the granitization of
The crust about 2,000 m.y. ago. The rocks were rejuvenated 1,300 m.y. ago, and again at the end of the Brazilian Cycle, 540 m.y. ago.

Of considerable interest are the post-orogenic granites (450-500 m.y.) which have been emplaced preferentially in the Santa Quitéria Massif while bodies of reduced size occur in the Jaguaribeian Fold Belt.

The emplacement of these granites was controlled by extensive regional faulting, and especially those faults formed by compressional release. Some of these intrusive granites possess high values of $\text{U}_3\text{O}_8$ (10 to 100 ppm) as well as concentrations of $\text{P}_2\text{O}_5$ (0.65 to 1.3%) which exceed those normally found in granites.

3.6 The Itataia Deposit

The Itataia deposit is located in the U-P District of the central part of the State of Ceará, about 45 km southeast of the town of Santa Quitéria, and about 170 km southwest of Fortaleza. The surrounding countryside is hilly and the exposure is good.

The principal country rocks surrounding the Itataia deposit are paragneisses (sillimanite-garnet-biotite gneiss) in addition to a large carbonate lens at least 10 km in length in the Jaguaribeian Fold Belt. Both the gneisses and the carbonates are cut by several granitic and pegmatitic apophyses in addition to a small granite cupola. These intrusives have been affected extensively by deuteric processes (FIG. 19 and 20).

Two ore types have been recognized. The first one consists of uniform masses of collophane and the second one of collophane veinlet and stockwork in marbles, in "episyenites" in gneisses as well as impregnations in these rocks. Uranium
occurs in the cryptocrystalline hydroxy-apatite which is also of commercial interest as phosphate ore. The rock in which this mineral occurs has been referred to as collophanite. The uranium is evenly distributed in this, and two genetic interpretations have been proposed concerning the nature of the uranium in the collophane. The first is that calcium has been isomorphously replaced by uranium in the collophane structure. The second viewpoint holds that the uranium is associated with finely dispersed oxides or that it has been absorbed by the collophane. However, it is important to note that no discrete uranium species has been found as yet.

The mineralization of the Itataia deposit has been described fully by Angeiras et alii (1978), and Forman & Angeiras (1979) who considered that the mineralization had evolved at least during four episodes or stages.

- Intense hydraulic fracturing of the country rocks
- Intense magmatic activity of a deuteric nature
- Local deformation of the country rocks accompanied by the formation of "episyenites".
- Extensive deposition of cryptocrystalline hydroxy-apatite and, in addition, a widespread replacement of the calcite and feldspar by phosphate in the marbles and "episyenites" respectively.

Present Reasonably Assured Reserves for the Itataia deposit are 83,000 tonnes U3O8 and Estimated Additional of 39,500 tonnes. The P2O5 reserves exceed 13,400,000 tonnes.

The U3O8 and P2O5 contents of the different ores are:

- Collophanite: 0.15 to 0.9% U3O8 and 20 to 38% P2O5
- Marble (Stockworks) and gneiss: 0.04 to 0.10% U3O8 and 5 to 15% P2O5
The unusual uranium-phosphorous mineralization at Itataia bears similarities with the uranium-rich apatite deposits of the USSR as described by Kazansky and Laverov (1977). The uranium is associated with cryptocrystalline apatite and other features in common include albitization, chloritization, dequartzification as well as the presence of trace elements (Y, La, Zr etc.). The studies in the area are underway and presently NUCLEBRAS started building up a pilot plant for 50 t U3O8/y and 5,000 t P2O5/y.

Besides the deposits at Itataia, there are several very promising prospects in the neighbourhood of the Central-Ceará Uranium-Phosphate District. These are known as Aquiri, Taperuaba, Mufumbo, etc. However, it is important to stress that the mineralization at these prospects occurs as disseminations in "feldspathic episyenites" which are characterized by intense albitization, chloritization, hematitization and dequartzification. The uranium is present in well formed crystals of fluor-apatite which occurs as fillings in vuggs caused by the dequartzification. These prospects are presently being studied in detail.

This type of mineralization is now known to occur all over north-eastern Brazil and it is believed that this was one of the most important metallogenetic events for uranium in South America. It is thought to be time related to the late and post orogenic granites which were intruded towards the end of the Brazilian Cycle (540 to 460 m.y.) (Angeiras et alii, 1978).

4. CONCLUSIONS

A recent OECD-IAEA publication (Anon, 1978) divided the major uranium deposits of the world into six categories of ore types.

1. Quartz-pebble conglomerate deposits
2. Proterozoic unconformity-related deposits
3. Disseminated magmatic, pegmatitic and contact deposits in igneous and metamorphic rocks
4. Vein deposits
5. Sandstone deposits
6. Other types of deposits including uranium-rich phosphates, uranium in bituminous shales, calcretes, duricrusts etc.

Nearly all of the above categories of deposits have been found in South America, and most of these occur in Brazil. Several of the above categories occur in Argentina, while in the Andean Countries of Chile, Bolivia, Peru and Colombia, uranium is found most frequently in vein deposits and in association with metallic sulphides. The uranium occurrences in Uruguay, Paraguay, Venezuela, Guyana, French Guyana, Surinam and Equador are considered to be insignificant at present as compared to those in other South American countries although the potential in some of these countries is appreciable.

According to the Nuclear Exchange Corporation (NUEXCO, June 1979), the South American uranium reserves are smaller than those of North America, Africa and Australia. They are larger than those of Europe and India while no figures were given for the Soviet Union, China and Eastern European countries. The South American uranium resources (Reasonably Assured at US$ 50.00 per pound or less) were given as:

<table>
<thead>
<tr>
<th>Country</th>
<th>Amount (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>120,000</td>
</tr>
<tr>
<td>Argentina</td>
<td>18,000</td>
</tr>
</tbody>
</table>

The figures for Brazil are similar to those issued by the Brazilian authorities, but those given for Argentina by Rodrigo and Belluco are larger (FIG. 21).

Quartz-pebble conglomerate deposits are known only in Brazil. They occur in the Quadrilátero Ferrífero of Minas Gerais as well as in the Serra de Jacobina of Bahia.
Proterozoic unconformity-related deposits have not been found yet in South America. However, favourable geological environments exist in Brazil as well as in neighbouring countries bordering the Amazon Craton.

The category of disseminated magmatic, pegmatitic and contact deposits in igneous and metamorphic rocks has limitations in that it includes deposits of very different geological characteristics, in addition to which there may be some overlap with the category of vein deposits including the unusual or unique deposit of the type found at Itataia in which uranium occurs in massive collophanites. In Brazil, the deposits of this category occur in Precambrian metamorphic rocks of the Central Ceará Uranium-Phosphate District, in the Seridô region and at the Lagoa Real District of the Espinhaço Province in the State of Bahia. These mineralizations occurred during the Brazilian Cycle. Disseminated uranium mineralization of Upper Cretaceous age is found in the Alkaline Complex of Poços de Caldas in addition to vein mineralization and epigenetic mineralization below the oxidation-reduction front. Elsewhere in South America, the category of disseminated uranium mineralization is found at single prospects in the Cacheuta and Sierra Pintada areas of Argentina, where the mineralization occurs in Permo-Triassic granites and in Triassic tuffs respectively. In the Sevaruyo District of Bolivia, disseminated uranium is found in Tertiary tuffs and in Tertiary limestones at the Peruvian mine of Colquijirca. Uranium mineralization of the disseminated type occurs in the metamorphic terrains of the Santander Massif of Colombia and probably elsewhere in the base and precious metal mines of the Andean zone in association with vein deposits. However, by far the largest of this category of deposits are those which are found in Brazil where the potential for further large deposits is considerable.

Vein deposits are those which occur as fillings in fissures, fractures and in pore-spaces of breccias and stockworks. This category of deposit is common in Argentina, Bolivia, Peru and
Chile. In Brazil, economic deposits of this category are found in tufficitic breccias at Poços de Caldas while occurrences are known in the Precambrian granitic rocks of the Seridô region, the Quadrilâtero Ferrifero and Brusque. In Argentina, vein-type mineralization has been found in igneous, metamorphic and sedimentary rocks of different ages from the Precambrian (?) to the Tertiary. However, with the exception of the deposits at San Sebastian, Urcal, Los Gigantes, Sierra de Comechingones and the Soberania prospect of the Papagayos District, these are of little economic interest.

The uranium in sandstone category of deposit is found in several South American countries in sediments from the Devonian (Amo-grinopolis, Brazil) to the Tertiary (Chuqui-Sur, Chile). The largest deposits are those found in Middle Permian continental sediments at Figueira, Brazil and in the Permian (?) continental sediments and volcanics of the Sierra Pintada District of Argentina. Small economic deposits are found elsewhere in Argentina at Sierra Cuadrada, Paso de Indios, Malargue (almost exhausted), Los Colorados, Tinogasta and the Tonco-Amblayo Districts. The potential for this type of deposit is appreciable in most South American countries. However, perhaps the most interesting region and geological environment is that of the Tertiary volcanic and sedimentary sequences of the Andean zone, of which the deposits of the Sevaruyo District of Bolivia are a good example.

The potential for uranium in calcretes and duricrusts is fair in some South American countries and especially in Argentina along the valley of the Rio Conlaria and in the Antofagasta area of Chile. Other types of uranium occurrence include the uranium-rich phosphatic sediments (Devonian) of the Piaui-Maranhão Basin and the Upper Cretaceous marine phosphorites of the Olinda area but these are not considered to be of interest at present.

As we know, only Brazil and Argentina have had
uranium exploration programs for any appreciable length of time. The geographical distribution of the deposits, prospects and occurrences in South America is a function of the investment made in exploration and accessibility. Even in Brazil, where uranium exploration has been carried out for the past thirty years, the more inaccessible parts of the country remain to be explored.

Further investment in uranium exploration is expected to lead to the discovery of more deposits of types which already occur. In addition to this, there exists a fair chance that unique or very unusual types of deposits, not previously known or scarcely known in South America as well as in other parts of the world, will be discovered. The deposits at Itataia and Poços de Caldas are precedents. Finally, the development of new concepts could lead to a reexamination and reevaluation of many occurrences not considered to be of economic interest at present.

5. ACKNOWLEDGEMENTS

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For the advice on Brazil's Nuclear Power Program we wish to thank Dr. J. M. A. Forman, Director of NUCLEBRAS.
REFERENCES


GLIKSON, A. Y. (1976) - Archean to Early Proterozoic Shield Elements; Relevance of Plate Tectonics, Geol. Assoc. of Canada, Special Paper NO 14, pp. 489-516.


FIG. 1

BRAZILIAN NUCLEAR PROGRAMME
FIG. 2
ORGANIZATION AND FUNCTIONS OF THE NUCLEAR SECTOR

PRESIDENT OF BRAZIL
NUCLEAR POWER POLICIES

MINISTRY OF MINES AND ENERGY
PLANNING, EXECUTION, AND CONTROL OF THE NUCLEAR POWER PROGRAM

NATIONAL NUCLEAR ENERGY COMMISSION
1. LICENISING
2. STANDARDS
3. INSPECTIONS
4. R & D (BASIC)
5. PERSONNEL DEVELOPMENT

NUCLEBRAS
1. MONOPOLY
   URANIUM PROSPECTION, EXPLORATION, MINING, MILLING, ENRICHMENT,
   FUEL FABRICATION, REPROCESSING, COMMERCIALIZATION OF NUCLEAR MATERIAL
2. REACTOR COMPONENT FABRICATION
3. PROMOTION OF BRAZILIAN INDUSTRY
4. NUCLEAR POWER PLANT ENGINEERING AND CONSTRUCTION
5. R & D (TECHNOLOGY)

ELETROBRAS
1. PLANNING FOR NUCLEAR POWER
2. ELECTRIC POWER UTILITIES
3. OPERATION
### FIG. 3

**NUCLEAR POWER PLANTS CONSTRUCTION SCHEDULE**

<table>
<thead>
<tr>
<th>NUCLEAR POWER PLANTS</th>
<th>LOCAT.</th>
<th>YEARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANGRA - 2</td>
<td>ANGRA</td>
<td>61</td>
</tr>
<tr>
<td>ANGRA - 3</td>
<td>ANGRA</td>
<td>69</td>
</tr>
<tr>
<td>NUCLEAR - 4</td>
<td>SP</td>
<td>61</td>
</tr>
<tr>
<td>NUCLEAR - 5</td>
<td>SP</td>
<td>69</td>
</tr>
<tr>
<td>NUCLEAR - 6</td>
<td>B</td>
<td>69</td>
</tr>
<tr>
<td>NUCLEAR - 7</td>
<td>B</td>
<td>69</td>
</tr>
<tr>
<td>NUCLEAR - 8</td>
<td>C</td>
<td>69</td>
</tr>
<tr>
<td>NUCLEAR - 9</td>
<td>C</td>
<td>69</td>
</tr>
</tbody>
</table>

**CAPTION**

- SITE PREPARATION: (16/24 MONTHS)
- PRE-CONSTRUCTION: (16/13 MONTHS)
- CONSTRUCTION: (74 MONTHS)
**FIG. 4**

URANIUM EXPLORATION DATA

<table>
<thead>
<tr>
<th></th>
<th>PRE-NUCLEARIS</th>
<th>NUCLERAS</th>
<th>TOTAL NUCLERAS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BEFORE 1975</td>
<td>76</td>
<td>77</td>
</tr>
<tr>
<td>AERIAL RADIOAERIAL SURVEYS (M2)</td>
<td>727,767</td>
<td>2,000</td>
<td>335,000</td>
</tr>
<tr>
<td>GROSS RADIOACTIVITY (MB)</td>
<td>RA 10,657</td>
<td>2,056</td>
<td>542</td>
</tr>
<tr>
<td>GEOPHYSICAL SURVEYS (ft of Seismic)</td>
<td>RA 364</td>
<td>2,541</td>
<td>12,265</td>
</tr>
<tr>
<td>SURFACE DRILLING (ft)</td>
<td>463,217</td>
<td>43,950</td>
<td>39,241</td>
</tr>
<tr>
<td>CHEMICAL ANALYSESES (DD)</td>
<td>66,326</td>
<td>11,965</td>
<td>73,730</td>
</tr>
<tr>
<td>GEOLOGICAL SURVEYS (ft)</td>
<td>RA 920</td>
<td>66,600</td>
<td>183,450</td>
</tr>
<tr>
<td>EXPENDITURES IN EXPLORATION (US$ 10^3)</td>
<td>96,355</td>
<td>8,583</td>
<td>13,523</td>
</tr>
<tr>
<td>EXPENDITURES IN MINS. EXPLOR., ORE</td>
<td>RA 1,844</td>
<td>1,364</td>
<td>2,542</td>
</tr>
<tr>
<td>PROCESSING DEVELOPMENT, ECONOMIC</td>
<td>-</td>
<td>-</td>
<td>7,000</td>
</tr>
<tr>
<td>EVALUATION, ETC (US$ 10^7)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

RA - NOT AVAILABLE
* - PLANNED

**FIG. 5**

EMPLOYMENT IN URANIUM EXPLORATION

<table>
<thead>
<tr>
<th>PERSONNEL</th>
<th>PRE-NUCLEARIS</th>
<th>NUCLERAS</th>
<th>NUCLAN</th>
<th>TOTAL NUCLERAS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>52/60</td>
<td>61/65</td>
<td>67/70</td>
<td>72/74</td>
</tr>
<tr>
<td>ECONOMISTS</td>
<td>-</td>
<td>31</td>
<td>34</td>
<td>43</td>
</tr>
<tr>
<td>ELECTRICIANS</td>
<td>5</td>
<td>4</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>SCIENTISTS, ETC</td>
<td>3</td>
<td>6</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>TOTAL</td>
<td>8</td>
<td>41</td>
<td>45</td>
<td>64</td>
</tr>
</tbody>
</table>

**TABLE:**

<table>
<thead>
<tr>
<th></th>
<th>PRE-NUCLEARIS</th>
<th>NUCLERAS</th>
<th>NUCLAN</th>
<th>TOTAL NUCLERAS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>52/60</td>
<td>61/65</td>
<td>67/70</td>
<td>72/74</td>
</tr>
<tr>
<td>ECONOMISTS</td>
<td>-</td>
<td>31</td>
<td>34</td>
<td>43</td>
</tr>
<tr>
<td>ELECTRICIANS</td>
<td>5</td>
<td>4</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>SCIENTISTS, ETC</td>
<td>3</td>
<td>6</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>TOTAL</td>
<td>8</td>
<td>41</td>
<td>45</td>
<td>64</td>
</tr>
</tbody>
</table>
NUCLEBRAS
EMPRESAS NUCLEARES BRASILEIRAS S.A.

BRAZILIAN URANIUM RESERVES
TONNS OF U₃O₈

OCTOBER / 80


240,000
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0

REASONABLY ASSURED
ESTIMATED ADDITIONAL
TOTAL
### FIG. 3

**BRAZILIAN URANIUM RESERVES. TONS OF U₃O₈ (OCT/80)**

<table>
<thead>
<tr>
<th>URANIUM DEPOSIT LOCATIONS</th>
<th>CLASS OF RESERVE</th>
<th>1979</th>
<th>1980</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>REASONABLY ASSURED</td>
<td>ESTIMATED ADDITIONAL</td>
<td>TOTAL</td>
</tr>
<tr>
<td>1 - PLANALTO DE POCOS DE CALDAS / MG</td>
<td>20,000</td>
<td>6,000</td>
<td>26,800</td>
</tr>
<tr>
<td>1.1 - CERCADO DEPOSIT</td>
<td>17,200</td>
<td>4,800</td>
<td>21,800</td>
</tr>
<tr>
<td>1.2 - OTHER DEPOSITS (AGOSTINHO, ETC)</td>
<td>2,800</td>
<td>2,200</td>
<td>5,000</td>
</tr>
<tr>
<td>2 - FIGUEIRA / PR</td>
<td>7,000</td>
<td>1,000</td>
<td>8,000</td>
</tr>
<tr>
<td>3 - QUADRILATERO FERRIFERO / MG</td>
<td>5,000</td>
<td>10,000</td>
<td>15,000</td>
</tr>
<tr>
<td>4 - AMORINOPOLIS / GO</td>
<td>2,000</td>
<td>3,000</td>
<td>5,000</td>
</tr>
<tr>
<td>5 - CAMPOS BELOS-RIO PRETO / GO</td>
<td>500</td>
<td>500</td>
<td>1,000</td>
</tr>
<tr>
<td>6 - ITATAIA / CE</td>
<td>83,000</td>
<td>39,500</td>
<td>122,500</td>
</tr>
<tr>
<td>7 - LAGOA REAL / BA</td>
<td>3,500</td>
<td>23,500</td>
<td>27,000</td>
</tr>
<tr>
<td>SUB-TOTAL</td>
<td>121,000</td>
<td>84,300</td>
<td>205,300</td>
</tr>
<tr>
<td>8 - ESPINHARAS / PB</td>
<td>5,000</td>
<td>5,000</td>
<td>10,000</td>
</tr>
<tr>
<td>SUB-TOTAL</td>
<td>5,000</td>
<td>5,000</td>
<td>10,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>126,000</td>
<td>89,300</td>
<td>215,300</td>
</tr>
</tbody>
</table>

© NEA - IAEA CLASSIFICATION
NUCLEBRÁS

URANIUM DEPOSIT LOCATIONS

FIG. 9

CAMPOS BELOS
RIO PRETO

ITATAIA

ESPINHARAS
(NUCLAIM)

BRASILIA
LAGOA REAL

AMORINÓPOLIS

POÇOS DE CALDAS

QUADRILÁTERO
FERÍFERO

FIGUEIRA

RIO DE JANEIRO
FIG. 10

THE URANIUM PROSPECTS AND DEPOSITS OF THE PARANÁ BASIN BRAZIL
## STRATIGRAPHIC COLUMN OF THE FIGUEIRA REGION

<table>
<thead>
<tr>
<th>CHRONOSTRATIGRAPHY</th>
<th>LITHOSTRATIGRAPHY</th>
<th>LITHOLOGICAL DESCRIPTION</th>
<th>SEDIMENTARY STRUCTURES</th>
<th>DEPOSITIONAL ENVIRONMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PALEOZOIC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PERMIAN</strong></td>
<td><strong>Tubarão</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Bonito</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Río</strong></td>
<td>Siltstones, yellow to grey, fine, grainy with intercalations of grey limestones and shales; sandstones, yellowish to grey, fine to coarse grained with horizons of coal at the base</td>
<td>PARALLEL LAMINATION, FLAT STRUCTURES, CROSS AND OBlique STRATIFICATION</td>
<td>MARINE REGRESSIVE, MARINE TRANSGRESSIVE, CONTINENTAL FLUVIAL AND GELTAR</td>
</tr>
<tr>
<td></td>
<td><strong>Serra Alta</strong></td>
<td>ASSILITE, DARK GREY TO BLACK</td>
<td>PARALLEL LAMINATION</td>
<td>RESTRICTED MARINE</td>
</tr>
<tr>
<td><strong>UPPER</strong></td>
<td><strong>Passa Dos</strong></td>
<td>LIMESTONE, DARK GREY; ARGILITE, BLACK, SHALES, BIMINUSOUS.</td>
<td>PARALLEL LAMINATION</td>
<td>RESTRICTED MARINE</td>
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<td><strong>Iratí</strong></td>
<td>SEDIMENTATION, MARINATED BY WAVE</td>
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<td></td>
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<tr>
<td></td>
<td><strong>Palermo</strong></td>
<td>SEDIMENTATION, MARINATED BY WAVE</td>
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**Note:** The table represents a comprehensive stratigraphic column of the Figueira region, detailing the lithological characteristics, sedimentary structures, and depositional environments across various formations and groups.
FIG. 12
POÇOS DE CALDAS ALKALINE COMPLEX
GEOLOGICAL MAP

- PHONOLITE
- POTASSIC ROCK
- FAYAITE
- TINGUÁITE
- TUFFS
- LUJAURITE / CHIBINITE
- FENITE / GNEISS
- SANDSTONE

FINGUÁITE RING DIKE
CONTACTS
FAULTS
FIG. 13
SIMPLIFIED EVOLUTION OF POÇOS DE CALDAS COMPLEX.

1. UPLIFT OF THE BASEMENT

2. DEVELOPMENT OF LAVA CONES AND PYROCLASTICS.

3. CALDERA-LIKE SUBSIDENCE

4. ENPLACEMENT OF NEPHELINE SYENITES, TROUVANTES, PHONOLITES

5. RING DYE FORMATION

6. INTRUSION OF JULAUERITES, CHIBINITES AND POTArites.
Genesis and principal lithological types and uranium minerals of the alkaline complexes of Kvanefjeld (Greenland), Pilansberg (Republic of South Africa) and Poços de Caldas (Brazil).

(a) Data from Sorensen et alii (1974). Nielsen and Steenfelt (1979);
(b) Data from Lurie (1979).
FIG. 15
THE O. UTSUMI MINE
DIAGRAMATIC CROSS-SECTION OF THE A, E AND B ORE BODIES

LEGEND
- STAIN
- MINERALIZED BRECCIAS
- TINNITE/PHONOLITE
- OXIDIZED ZONE
- PYROCLASTIC ROCES
- "AMAS"
- URANIUM NODULES
- FAULTS

DIAGRAMATIC - NO SCALE
R.C. SANTOS, 1978
FIG. 17
LAGOA REAL URANIUM DISTRICT
ORE BODY № 03
FIG. 18
CENTRAL CEARA' URANIUM-PHOSPHATE DISTRICT
GEOLOGICAL SKETCH MAP

JAGUARIPARE FOLDED FOLK
+ + SANTA LUNITAIA MIDDLE MASSIF
FAULTS
FRACTURES
STRUCTURAL TRENDS

P-V ANOMALIES:
• CAR-BORNE
• AIR-BORNE

AFTER FORD AND ROGERS (1970)
FIG. 19
ITATAIA DEPOSIT
GEOLOGICAL MAP

[Diagram showing geological features with legend: soil cover, felspathic and/or sedimentary rocks, contacts, synformal structures, massive collophaneite, samples, incised, stockwork zone, faults, antiformal structures]
FIG. 20
ITATAIA DEPOSIT
GEOLOGICAL CROSS-SECTION

LEGEND

- COLLOPHANITE ZONE
- MARBLE WITH IMPREGNATION OF COLLOPHANE
- INFERRED CONTACT
- INFERRED NORMAL FAULT
- DISSEMINATION AND STOCKWORK ZONES
- GNEISS WITH IMPREGNATION OF COLLOPHANE
- DDH

F. 12
FIG. 21

URANIUM RESERVES OF ARGENTINA
TONNES U₃O₈

<table>
<thead>
<tr>
<th>CATEGORIES</th>
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<th>TOTALS</th>
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<tr>
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<td>&lt; 80</td>
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<td>REASONABLY ASSURED RESERVES</td>
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<td>ADDITIONAL ESTIMATED RESERVES</td>
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<tr>
<td>TOTALS</td>
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<td>12,000</td>
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FROM: RODRIGO AND BELLUCO (1978)