Reactor BR2

POL GUBEL

INTRODUCTION

The BR2 is a materials testing reactor and is still one of SCK•CEN's important nuclear facilities. After an extensive refurbishment of 22 months to compensate for the ageing of the installation, to enhance the reliability of operation and to comply with modern safety standards, we restarted the reactor in April 1997. During the last three years, we maintained the availability of the installation at an average level of 97,6 %. This demonstrates clearly the success of the refurbished plant.

Routine maintenance activities and inspections guarantee the continued safe and reliable operation and provide the basis for a secure long-term future.

The annual operating regime is restricted to 5 standard cycles of 21 days at power. This rather low utilisation of such a large facility is imposed by a budgetary constraint. We promote an extended utilisation by offering well-adapted services for internal and external scientific users and by developing new capabilities for commercial productions.

As before, we used extensively the CALLISTO loop, a high temperature, high pressure water loop in BR2 to simulate PWR conditions. We use it for various programmes involving LWR, pressure vessel materials, IASCC (Irradiation Assisted Stress Corrosion Cracking) of LWR structural materials, fusion reactor materials and martensitic steels for use in ADS (Accelerator Driven System) systems. We focussed the development of new irradiation devices on emerging needs. Most of the work concerned multipurpose reusable rigs for materials irradiation under high fast neutron fluxes, a dedicated irradiation rig for the qualification of advanced MTR (Materials Testing Reactor) fuels and the concept study of a new irradiation basket with instrumented LWR-advanced fuel pins to be loaded in one in pile section of CALLISTO.

In 2001 and beyond, new irradiations on IASCC, fusion and ADS materials and advanced LWR fuels will be started in the CALLISTO loop and in a new reusable and instrumented rig called MISTRAL. The IPS2 (In Pile Section 2) of CALLISTO loaded in the core region and delivering the highest fast fluxes under PWR conditions, is booked for the next 2 years.

An *internal R&D programme aims at improving the* BR2 utilisation. It focuses on the improvement of online in-core instrumentation (i.e. self powered neutron detectors, fission chambers, gamma thermometers ... integrated in the DOLMEN and FICTIONS irradiation rigs), data acquisition (system BIDASSE for BR2 nuclear and process data and for instrumented experiments) and the development of adapted neutronics/ hydraulic computer models. Beginning in 2001, a benchmark experiment is scheduled for at least one reactor cycle to validate the predictions of sophisticated Monte-Carlo calculations.

BR2's commercial programmes are of prime importance because they help to finance the reactor. It is expected that the income from radioisotopes will still increase with the recent expansion in capacity for Mo99 production. At the same time, BR2's position in the world market is being enhanced by the introduction of new, added value products such as $^{188}W/^{188}Re$, which take advantage of the unique and extremely favourable characteristics of the reactor in terms of neutron flux and irradiation volumes. 2000 was a good year for the production of NTD-silicon at BR2. After years of stagnation since 1997, the market is exploding and the prospects for 2001 and later look still more favourable. In close collaboration with CEA (France), we approached potential customers and we signed long term contracts. Adequate resources are made available which will enable the SIDONIE (Silicon Doping by Neutron Irradiation) facility to return to its maximum production capacity early in 2001.

Reactor Operation

Exploitation

The reactor was operated for a total of 104 days at a mean power of 56 MW in order to satisfy the irradiation conditions of the internal and external programmes using mainly the CALLISTO PWR loop.

The availability of the installation reached an acceptable level of 93,0 % (compared with 99.97 % in 1999) during operation. However, in 2000 the first three cycles were indeed each interrupted for a few days by: a human error whilst rinsing a filter in the first cycle which caused a fast depressurisation of the reactor primary cooling circuit, a spurious electronic fault in the scram line during the second cycle, and a leak detected in cycle 03/00 inside an instrumented irradiation rig loaded in one IPS (In Pile Section) of the CALLISTO loop. The incidents involving the primary depressurisation in cycle 01/00 and the burnout of a relay (situated under the reactor control room) during the shutdown of cycle 05/00 were reported to the safety authorities and included in our INRIBUAN (*IN*cident, RIsk and BUdget ANalysis) reporting system. These two incidents were classified 0 on the INES (International Nuclear Event Scale) scale.

Remedial modifications are now underway to prevent an inadvertent depressurisation of the primary cooling circuit and an extensive inspection of all main relay boards is also being carried out to eliminate the prospect of other relays becoming subject to the possibility of burnout.

The Irradiation Group responsible for the production of radioisotopes and NDT (Neutron Doping by Transmutation) Silicon was transferred to the Exploitation Group to optimise the co-ordination of all operators responsible for manipulations on the reactor and transportations.

The responsibility for the exploitation of the CALLISTO loop – up to now under the responsibility of the Reactor Experiments Department – is being transferred to the Exploitation Section of the BR2 Department. A new BR2 staff member has been specially trained and qualified in 2000.

Fuel cycle

The mean consumption of fresh fuel elements was 5,32 per 1000 MWd in 2000. This figure is comparable to those obtained in previous years.

The first batch (20 elements) of 73 % ^{235}U enriched fuel elements, that were made at UKAEA-Dounreay using recovered uranium from BR2 spent fuel, was further irradiated until reaching their discharge burnup. The shutdown of all main fuel cycle activities in Dounreay prevents any further reuse of BR2's recovered HEU (Highly Enriched Uranium) inventory which still remains available for reprocessing at the Dounreay site.

Standard UAlx 93% ^{235}U fuel elements are still used and will continue to be fabricated from available feed stocks until the new LEU (Low Enriched Uranium) U-Mo high density fuels, that are now under development by ANL (Argonne National Laboratory) have been completely qualified for use in BR2.

A license for the new TN-MTR cask has been granted by the Belgian Licensing Authorities. This enabled five batches of fuel elements to be transported to La Hague for reprocessing. A total of 442 fuel elements, or about 50 % of the stored inventory have already been transferred under the contract signed with COGEMA.

Refurbishment

Only a few projects were continued in the phase 5 of the refurbishment programme and will be finalised in 2001:

- Fire prevention and mitigation: improvement to the isolation of the different compartments in the containment building with special attention to the power and instrumentation cable penetrations between compartments.
- Mitigation of consequences from an earthquake: instead of installing a sacrificial joint between the ventilation pipe-bridge and the reactor building isolation valves, as proposed earlier, reinforcement with additional steel girders is now foreseen to avoid a horizontal displacement between the structures in the event of a seismic incident.
- Automatic regeneration of the Pool Ion Exchangers and the recuperation of effluents from the monitoring system.

Maintenance

Besides normal maintenance work, we made special interventions to repair a diesel emergency group and to provide full automation of the water treatment plant for demineralised water.

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We installed a ultra-violet disinfection unit in the water purification circuit of the reactor pool.

We made a study to lock specific valves when filters of the purification circuit are rinsed to avoid inaccurate manipulation. The necessary modifications will be implemented in 2001.

From the second half of 2001, the reactor maintenance group will also be responsible for the total maintenance of the experimental loop CALLISTO; an exchange of knowledge with the reactor Experiments Department begun and special training of personnel is foreseen.

Training

As foreseen in the Safety Analysis Report, we organised training sessions (523 man-days in total) to fulfil the minimum requirement of 10 days per year per operator.

These sessions combined technical, theoretical (353 man-days) as well as practical aspects (114 man-days). BR2 organised a specific programme on the CALLISTO loop to provide operation supervisors with approved instructions on its use (56 man-days).

The programme for the training sessions is scheduled one year in advance; its content and a global summary report, after execution, are submitted to the Regulator for evaluation.

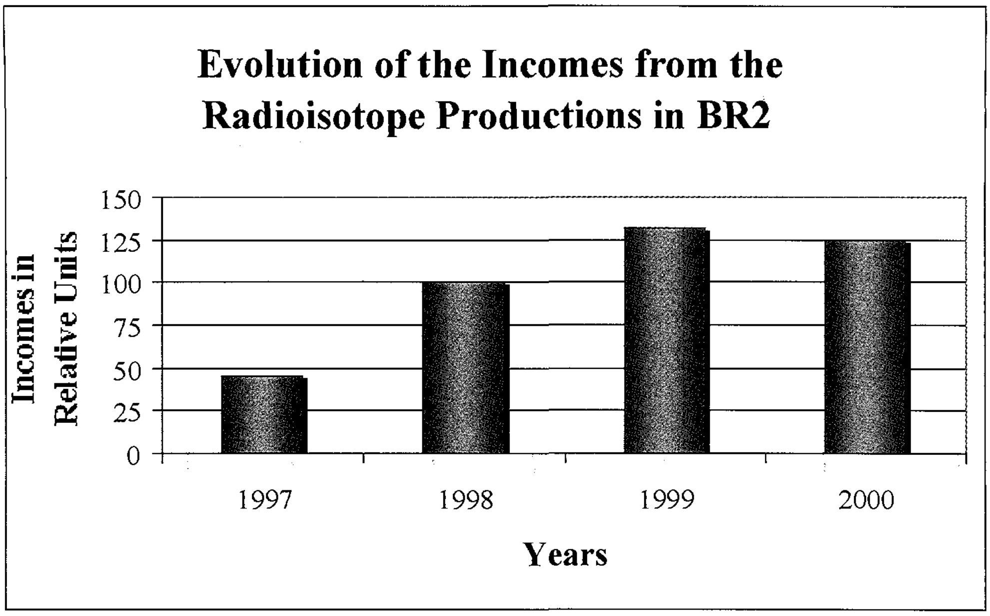
A special report with a global summary of the training programme from 1997 until 2000, has also been established and submitted to the Evaluation Committee where BR2 staff and the Regulator are represented. On this basis, the license for the BR2 operators and the operation supervisors was renewed for another three years.

Production of Radioisotopes

We produce radioisotopes for various applications in the nuclear medicine (diagnostic, therapy, palliation of metastasis bone pain), industry, (radiography of welds...), agriculture (radiotracers...) and for basic research. Due to the availability of high neutron fluxes (thermal neutron flux up to 10^{15} n/cm^2.s), the BR2 reactor is considered as a major facility through its contribution for a continuous supply of products such as ^{99}Mo (^{99m}Tc), ^{131}I, ^{133}Xe, ^{192}Ir, ^{186}Re, ^{153}Sm, ^{90}Y, ^{32}P, ^{188}W (^{188}Re), ^{203}Hg, ^{89}Sr, ^{60}Co, ^{169}Yb, ...

Since the restart of the BR2 reactor in 1997, after its refurbishment in 1995-1997, the income from radioisotope production has increased considerably and stabilised as shown – in relative units - in the figure below. From 2001 we expect a new increase of income: indeed in 2000 we loaded in the reactor an additional irradiation device to enhance the position of the BR2 in the European market for the production of ^{99}Mo ($T_{1/2}$=66 h).

This is the major isotope produced in BR2 and it is used for the manufacture of ^{99}Mo/^{99m}Tc ($T_{1/2}$=6 h) generators. From 2001, it will be possible to routinely use up to five irradiation devices in the reflector channels, and these will provide a total irradiation



capacity of 36 highly enriched ^{235}U targets, i.e. 108 targets per reactor cycle.

We made a serious effort to take advantage of the high thermal neutron fluxes available in the central beryllium plug (up to 10^{15} n/cm^2.s). We performed test irradiations of highly enriched ^{186}W targets in 1998 with encouraging results for the production of ^{188}W ($T_{1/2}$=69 d) by double neutron capture. The ^{188}W activity produced has been used for the manufacture of $^{188}W/^{188}Re$ generators. Negotiations with various partners are ongoing in order to start a promising research project related to ^{188}Re ($T_{1/2}$=16.9 h) and its application. The BR2 reactor is actively involved in this project, which will include the enrichment of natural W in ^{186}W, the target irradiation and the production of an optimal generator for users. Several medical applications are considered for this technology such as in the field of cardiology and bone pain palliation. The use of liquid-filled balloons with ^{188}Re ($T_{1/2}$=16.9 h) is advocated as an attractive new therapeutic candidate in cardiology for uniform coronary vessel wall irradiation in order to inhibit the restenosis after percutaneous transluminal coronary angioplasty.

Production of NTD-Silicon

BR2 is ideally suited to the volume production of irradiated silicon for the semiconductor industry. This is carried out in a dedicated facility called SIDONIE (Silicon Doping by Neutron Irradiation). SIDONIE is located within the beryllium reflector and is designed to continuously rotate and traverse the silicon through the neutron flux. The speed at which the silicon is traversed through the reactor is computer controlled to ensure that the correct neutron dose is received. The effect of continuously rotating and traversing the silicon produces exceptional dopant homogeneity. SIDONIE can accommodate batches of silicon measuring 4-inch and 5-inches in diameter by up to 800 mm in length. For n-type silicon, the average axial and radial resistivity variation can be controlled within about 3% whilst the resistivities produced are normally within +/- 5 % of the specified (target) value.

During recent years, semiconductor device manufactures have opted to use newly developed "premium quality" chemically doped silicon as cheaper alternative to NTD material. This was primarily responsible for causing a significant downturn in world demand resulting in very low production levels in BR2 since 1997. Consequently, NTD prices have been forced down and this is partly responsible for its market recovery. This is because it has now become a cheaper option to premium chemically doped silicon for some applications of which the most notable are transistors as used in the potentially enormous market for domestic "flat-screen" televisions and the next generation of mobile phones.

In association with CEA, BR2 has successfully stimulated considerable market interest in its NTD-silicon production capability. This resulted in most of the world major silicon producers carrying out successful qualification tests in BR2 during 2000. In most cases this was quickly followed by ever increasing demands for volume production culminating in a throughput by the end of the year equivalent to approximately 90% of total capacity.

Long-term production contracts with clients suggest that BR2 will continue at this rate of production for the foreseeable future.

Scientific irradiations programmes

Objectives

The principal mission of the Department Reactor Experiments is to successfully achieve the practical realisation of scientific irradiation experiments in BR2 on behalf of its clients.

This work is mainly undertaken for external customers and/or R&D projects that are sponsored by SCK•CEN.

The department is specialised in the design, engineering, construction, instrumentation and operation of dedicated irradiation facilities. In these facilities experiments are currently undertaken for testing LWR fuels, LWR materials, fusion-reactor materials, special-purpose targets and even reactor safety oriented tests.

In 2000, we performed most of these irradiations in the CALLISTO PWR loop. The irradiations achieved or under preparation in 2000 are reported below, including the development of advanced facilities and concept studies for new programmes. The view of the experimentalist's for the different irradiation projects are reported in the chapters that describe the relevant R&D Departments. Here, emphasis is placed on the added values – both scientific and technological – to these projects, born by the Department Reactor Experiments and the Division BR2.

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Achievements

Experiments performed in CALLISTO PWR loop

The CALLISTO facility provides a purpose-made environment for the irradiation of LWR fuel and/or materials under realistic PWR conditions (flowing water, 155 bar, 300°C, PWR water chemistry). The loop comprises three in-pile sections in the BR2 reactor. In 2000 the facility has been in operation with different experimental loads.

The department for Reactor Material Research performed a defect tolerance analysis for predicting the allowable lifetime of the CALLISTO pressure tubes. The analysis was based on fracture mechanics and crack growth caused by IASCC. It took account of the actual irradiation history of the in-pile section No. 2 (IPS2) i.e. the IPS under the highest fast neutron flux. The study concluded that the IPS is capable of remaining in the reactor for 2000 days at full power. This conclusion was accepted by AVN (Association Vinçotte Nucléaire) and it effectively means that the IPS can stay in the reactor for another 50 reactor cycles.

In 2000 we carried out the following irradiation programmes:

1. The BACCHANAL programme; this consists of increasing the burn-up of nine MOX fuel rods that had been pre-irradiated in BR3. This was carried out in the in-pile section IPS1 of CALLISTO.

Taking advantage of intermediary results gained from this project, the accuracy of the method to determine on-line, the linear power in each individual fuel rod was improved. In order to refine this somewhat elaborate method, the following steps were taken:

- in the DORT calculations, the complete BR2 core loading was used instead of the previous half core loading that was centred on the relevant IPS;
- a 3-D neutronic calculation based on the Monte-Carlo model was used and applying the MCNP calculation code, the validation of the original model based on the thermal balance was continued;
- during the year, the calibration of each key detector involved in the measurement of the rod power was carefully checked and their accuracy assessed;
- the new data acquisition system BIDASSE efficiently scans more than 250 analogue and digital signals. All the raw data and all the calculated values are now on-line and available via the PC-network to each of the scientists in charge of the irradiation of an experimental target in the CALLISTO facility. They can then employ any of the statistical packages available to analyse the irradiation results.

The BACCHANAL programme will continue in 2001 and beyond. One of its objectives is to further qualify the CALLISTO loop for the THOMOX programme.

2. Also related to fuel testing, the feasibility of performing power transients on fuel rods in the CALLISTO loop was studied. This demonstrated that increasing the linear power in a single fuel rod from 300 W/cm to 600 W/cm in less than 3 minutes is possible in IPS2. However, because of the decontamination problems that could arise from a major rod failure, we decided to keep this possibility as a back-up solution and to look at ways that this experiment can be made to be more acceptable (by a detailed ALARA study, small modifications to the loop such as improvements to the feed/bleed system, devising specific procedures, etc).

3. In the framework of IASCC of LWR materials we performed the CORONA project in IPS2 of CALLISTO where the fast neutron flux (> 1 MeV) reaches values of about 1 10^{+14} $n.cm^{-2}.s^{-1}$. The aim of this experiment is to detect on-line crack initiation in pressurised tube specimens. We successfully developed a specific technique to strain these specimens up to 2.5 times the unirradiated yield stress at 300°C. Pressure tubes were loaded either statically by filling the tube with argon before irradiation or dynamically by external pressurisation during the BR2 operation.

In addition, we tested other new in-pile detectors developed by the IASCC research programme team, such as dissolved hydrogen sensors, electrochemical noise probes, etc. To accommodate this irradiation, the penetrations of the instrumentation wires through the IPS's head had to be modified. However, because of some problems with leak tightness at the penetration level, a new test programme had to be launched to fully qualify two alternative penetration techniques for further applications.

It is expected that the irradiation of CORONA will continue in 2001 to reach the requested fast fluence.

4. The IRFUMA (<u>IR</u>radiation of <u>FU</u>sion <u>MA</u>terials) experiment was irradiated at 300 °C in the D180 channel (IPS 2) of the CALLISTO facility during

cycle 05/2000. Dedicated to the better characterisation of the mechanical properties of candidate fusion materials after irradiation, the specimens are subsequently subjected to the following tests:

- tensile properties at different temperatures;
- impact toughness, with instrumented tests performed over a temperature range in order to derive the transition curve;
- static fracture toughness at different temperatures;
- possibly, dynamic fracture toughness at different temperatures;
- tests for determining the susceptibility of the irradiated material to stress corrosion cracking. These tests will be slow strain rate tensile tests (SSRT) in water. The test conditions will be in a fusion relevant environment: water temperature in the range of 100-250°C; degassed, possibly with addition of hydrogen or oxygen.

A second and third irradiation campaigns of IRFUMA for reaching higher fluence levels are scheduled to take place in 2001 and 2002.

Experiments in dedicated facilities

The test section of the MOL 7C/7 in-pile sodium loop was dismantled.

This safety experiment MOL7C/7 for the sodium cooled fast breeder reactor development was performed in BR2 in 1989. After Belgium and Germany withdrew the necessary funding for this programme, the experiment remained stored in the BR2 reactor deep pool. To enable the reprocessing of the fuel, it was necessary to drain the sodium from the bundle. However, during the original programme of tests, the bundle was seriously damaged thus requiring an adequate melt-out procedure.

Accordingly, a purpose-made installation was built consisting of a closed box in which the different parts of the test section could be heated up in an inert gas atmosphere to 365 °C. We collected the sodium (melting point 98°C) in a container. Because of the high radiation level, all operations had to be done remotely in the BR2 hot-cells. The sodium container, the drained bundle and the other parts of the test section are stored within a helium atmosphere in the BR2 storage canal. The Radioactive Waste and Clean-up Division are now performing tests for the final treatment of sodium and sodium contaminated components. Reprocessing and/or final storage of the fuel itself will be organised by FzK as contractually stipulated.

Experiments under preparation & development of rigs

GERONIMO project

Within the framework of the international programme GERONIMO, the Reactor Experiments and the Reactor Material Research Departments are undertaking preparatory work. Ten BWR MOX fuel rods are presently being irradiated to different burnup levels (up to 65 GWd/t) in a German power reactor. Extensive NDT and destructive tests on these rods will take place in the Laboratory for Medium and High Level Activity (LHMA) cells in Mol. Three segments will also be subject to power-transient testing in BR2. The PWC/CCD facility, which has already been used in the past for a large number of tests on PWR and BWR fuel, is being requalified for performing the transient tests for this programme in 2002.

THOMOX project

The study of a series of advanced nuclear fuels (all ceramic oxides containing $(Th,Pu)O_2$, $(U,Pu)O_2$ and UO_2) in the THOMOX project requires the irradiation of 2 times 8 fuel segments in the CALLISTO loop during a period of 4 years. This project offers an important scientific and technological challenge.

Eight fuel segments will be equipped with a pressure detector, using a LVDT technique (Linear Variable Differential Transformer), to follow the fission gas release and also with a high temperature thermocouple inserted at the segment bottom to measure the fuel central temperature. In addition, SPNDs (Self Powered Neutron Detector) and activation dosimeters are placed in the rig for the determination of the actual neutron flux and neutron spectrum, gamma-thermometers for measuring the gamma-heating rate and usual thermocouples. The 50-mm diameter plug will be designed to accept the penetration of 32 electrical cables using the experience gained from the CORONA experiment for its development and qualification.

The fuel bundle is divided into upper and lower parts, which contain eight instrumented and eight non-instrumented segments respectively; the latter can be unloaded for intermediate non-destructive testing. However, because the bundle is quite different from previous experiments that have been loaded in CALLISTO and because of the variety of fissile material composition of the segments, it will be necessary to thoroughly revise the on-line measurement procedure of the linear power in each fuel segment. Therefore, a detailed thermal balance will need to be devised based on an advanced thermo-hydraulic calculation code and the results of the 3-D MCNP calculations will need to be used as input data for determining accurately both the axial and the radial power distribution in each separate segment.

REVE project

The purpose of the REVE (Réacteur Virtuel d'Etude) project that is conducted a.o. by EDF and SCK•CEN is to simulate the mechanical behaviour of irradiated reactor pressure vessel steel. To validate the model that is elaborated, we will irradiate in 2001 about 2000 mini specimens from 10 different materials. Taking advantage of the flexibility of BR2 and of the CALLISTO facility, it will be possible to take up the challenge to reach material damage rates of 0.2, 0.1, 0.05 and 0.025 dpa in fast neutron fluxes of 1.10^{+14} $n.cm^{-2}.s^{-1}$ and 3.10^{+12} $n.cm^{-2}.s^{-1}$, in only 3 reactor cycles. The loading scheme for the specimens has been studied extensively to minimise the flux gradient between all the specimens from within the same batch. An important requirement is also to encapsulate these specimens, to avoid them reacting with CALLISTO's coolant water, while keeping a close control of their irradiation temperature.

SMIRNOF II project

A dedicated rig has been designed for the neutron-irradiation of optical fibres. In this so called SMIRNOF II programme quantitative data will be collected concerning the behaviour of optical fibres for diagnostics in fusion reactors in a mixed spectrum of gamma rays and neutrons. Although radiation-induced attenuation under gamma irradiation is rather well characterised, the effect of neutrons is to be studied further. The rig under construction will allow the irradiation up to a fast fluence of at least 10^{17} n/cm^2. The specimens will be air cooled in order to limit their temperature to maximum 150 °C. The irradiation test is scheduled to take place in the first half of 2001.

RIED 1 project

The purpose of the RIED (Radiation Induced Electrical Degradation) project is to study the degradation process of ceramic electrical insulators, induced by neutron damage at high temperature. Such insulators will be used in the fusion reactor vessel wall as part of the heating, current drives and diagnostic systems. Unusual and stringent testing conditions are required: neutron flux (10^{+12} $n.cm^{-2}.s^{-1}$, E > 0,1 MeV), gamma dose rate (100 $Gy.s^{-1}$), sample temperatures (350°C, 400°C and 450°C), vacuum level (10^{-5} bar) and electrical field (up to 500 V_{DC}). Also delicate electrical measurements (in-pile, on-line) are needed: electrical resistivity in the range 10^{+11} to 10^{+7} Ω.m and small currents of 0,02 nA to 0,2 mA.

The set-up of such an experiment and the design of a dedicated rig in a nuclear environment are quite challenging.

As to achievements in 2000, the construction of the complete RIED facility, i.e. the in-pile device and the control panels was terminated.

The figure below shows a detail of the samples assembly. We runed general functional tests as well as tests of the automatic controls and safety actions.

During these tests (under vacuum and high temperature) a contamination of volatile zinc and lead occurred on the surface of the ceramic samples. The source of these metallic elements was shown to be in the material of the electrical connectors that were supplied out of specification.

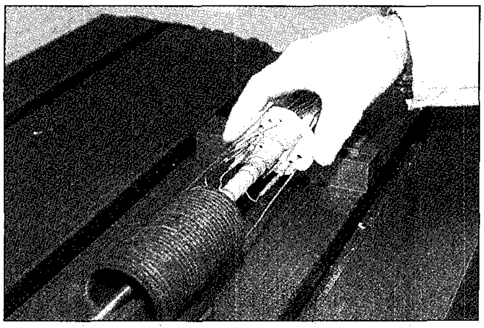
We implemented corrective actions (clean-up, replacements) in parallel with improving the vacuum level in the rig and additional lab tests to improve the electrical measurements. After repair and requalification the RIED 1 irradiation is scheduled for the first half of 2001.

Two follow-on RIED-type experiments are planned in 2001-2002.

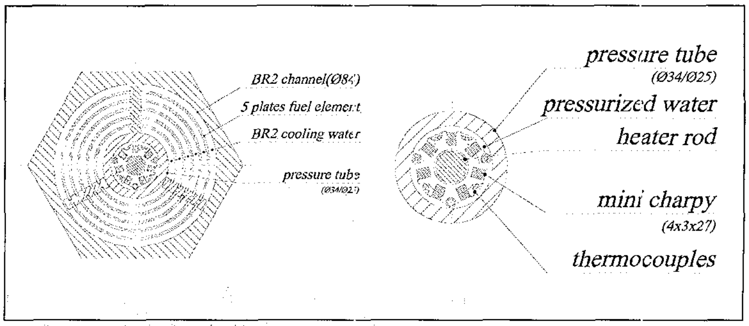
MISTRAL device

MISTRAL stands for Multipurpose Irradiation System for Testing of Reactor Alloys.

Its objective is to provide BR2 with a reusable device for the irradiation of metallic specimens (such as tensile and mini-Charpy specimens) under a fast neutron flux and in an extended temperature range of 200 – 350 °C with an accuracy of +/-5°C.



RIED ceramics samples with their wiring and heating part



Cross section of the MISTRAL irradiation device installed in a BR2 5 plates fuel element

In 2000, the pressurised water capsule and all its peripheral equipment was modelled and studied. Enclosed by a single thick pressure tube (designed for an internal water pressure of 155 bar), the in-pile section contains a basket that provides loading space for 91 tensile or mini-Charpy specimens, 5 dosimeters and 16 thermocouples. An electrical heating element is inserted in the axis of the basket. This element needs to be compact whilst providing a thermal heat flux of 100 $W.cm^{-2}$ and being capable to survive for long periods in the reactor; it is being developed specifically for MISTRAL.

We will install the rig inside a 5-plate fuel element of BR2. The next figure shows a cross section of the irradiation device. We will achieve the temperature regulation of the specimens and the control of the uniform temperature distribution among all the specimens by a combination of the gamma heating, the electrical heating power and the water pressure (thus acting on the water saturation temperature).

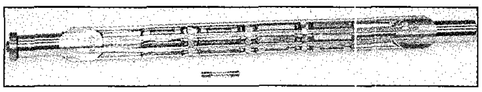
An appropriate design for holding the tensile or mini-Charpy specimens in a basket that also allows them to be loaded and unloaded in the hot-cells has been developed.

In 2001, two MISTRAL in-pile sections and associated out-of-pile equipment will be manufactured. They will first be used to irradiate structural materials at 200°C for the SPIRE project within the framework of the ADS development (in particular for the MYRRHA project). To reach damage doses of 3 and 6 dpa, these irradiations will take about 1 and 2 years respectively. Future utilisation is already foreseen for the irradiation testing of fusion reactor materials.

Reactor BR2: R&D programme

Objective

The aim of this programme is the improvement of the BR2 utilisation: refined determination of the irradia-



Full scale model of the basket that allows us to load and unload mini-Charpy specimens in the hot-cells

tion conditions, the development of new irradiation devices, improvement of the in-core instrumentation and data acquisition systems.

Achievements

Reactor physics

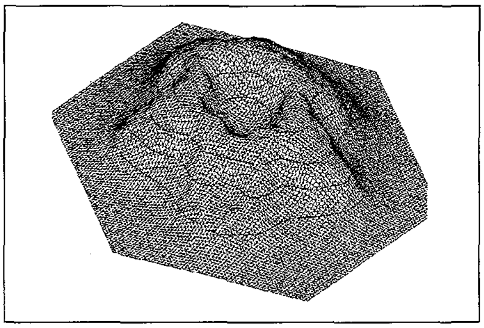
The development of the hexagonal 3D nodal diffusion code NH3D started some years ago. In 2000 the code has been rendered operational for steady state calculations.

A new option for assembly representation on the base of the developed quasi-refined model (QRM) was implemented. The main idea of the QRM is to apply the regular hexagonal grid with a finer lattice pitch and to cover separately every homogeneous region of each cell.

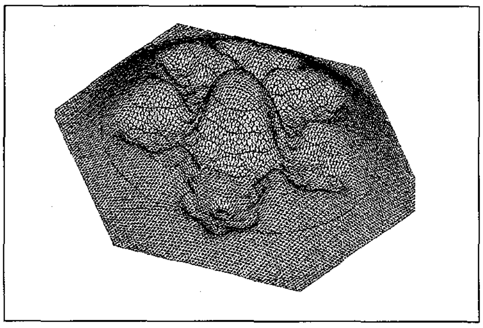
The macroscopic cross section (MCS) sets were generated using the new version of SCALE code system. The internal heterogeneous structure and the element neighbourhood are taken into account during macroscopic cross section calculation. The results show that when the QRM option is used, the calculated thermal and fast fluxes are very close to the experimental measurements.

In particular the NH3D code was applied for the evaluation of the irradiation conditions of two experimental MTR-type fuel elements.

The generation of the extended cross section library that started in 1999 in the frame of the post-doctorate work was continued in 2000.



BR2 fast flux shape in hot plate



BR2 thermal flux shape in hot plate

We calculated changes in the concentration of isotopes during the operation of BR2.

BR2 performed many investigations of the dependence of the MCS on the operational parameters for the burnup treatment. Based on the analyses of the results the most important parameters were determined and used in the MCS generation.

A dedicated method for generating the MCS for partially burned standard BR2 fuel elements was established and used for the creation of a library with MCS for fuel elements with various burn-up values.

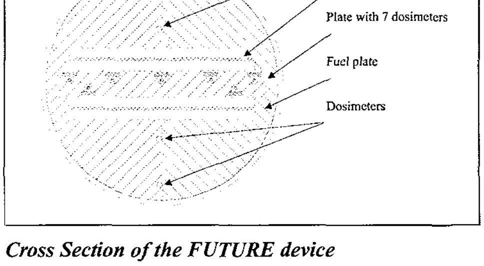
The work still ahead concerns 2D representation of the assembly and the arrangement of the MCS in directly usable formats.

MTR fuel qualification – the FUTURE project

New fuel designs for Material Testing Reactors require being qualified under representative conditions. FUTURE (FUel Test Utility for REsearch reactor) is a dedicated device for full-size fuel plate irradiations.

Its objective is to provide BR2 with a reusable device for the irradiation of fuel plates under representative conditions, such as geometry, neutron spectrum, heat flux and thermal-hydraulic conditions.

In 2000, we studied and designed the basket that contains the fuel plates. The basket is designed to be loaded with 2 fuel plates, a central plate containing 7 dosimeters and 4 peripheral dosimeters.



Cross Section of the FUTURE device

In 2001, we will manufacture the basket and verify its hydraulic behaviour in our H4 water loop facility. We will then perform a first benchmark irradiation of 2 UAl_x fuel plates of the standard MTR-type used for the standard BR2 fuel elements. The aim is to benchmark the various neutron-computing methods available for BR2 with the dosimeter results from this first irradiation and to qualify the irradiation device.

Development of in-pile instrumentation

This program aims at the selection and/or development of the most suitable sensor for physical, nuclear or electrochemical measurements in specific in-pile conditions. Our approach consists of a detailed modelling of all physical processes relevant to the sensor operation, combined with experimental irradiation campaigns.

In 2000 we concentrated on the on-line in-pile measurement of the neutron and gamma flux. A Monte Carlo model was developed to calculate the neutron and gamma sensitivity of SPND's (Self-Powered Neutron Detectors). This model is based on the Los Alamos MCNP code and provides a coupled transport calculation of neutrons, gammas and electrons, finally leading to a relation between the detector current and the flux. Prompt and beta-delayed sensitivities are calculated as a function of the neutron (or gamma) energy; provided the spectra are known, the overall sensitivity can be calculated. The model also includes the calculation of parasitic effects related to the influence of the immediate environment, the contribution of the signal cables, etc. Compared to the commonly applied analytical models, the Monte Carlo approach is more accurate and applicable to a much larger variety of detectors.

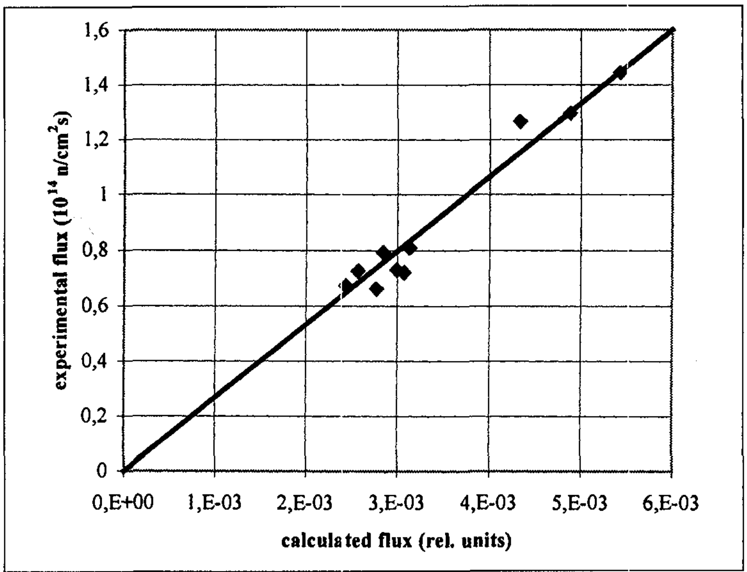
For Rh, Ag and V SPND's we developed a digital compensation technique to convert the delayed signals into instantaneous flux information, resulting in a response time decrease from several minutes to about 1 second (depending on the sampling rate).

For in-pile gamma detection so-called gamma thermometers are used. Using a similar Monte Carlo method we calculated the gamma sensitivity that is related to the gamma heating and the disturbing neutron sensitivity stemming from gammas created by neutron interactions in the detector sheath and from beta heating.

In the last BR2 cycle of 2000 the DOLMEN experimental device, containing several types of SPNDs and gamma thermometers, was irradiated in a reflector channel, in order to validate the developed models. On the basis of the calculated sensitivities, the detector signals are converted immediately into flux values. As a first result, the figure below illustrates a very good consistency between the neutron fluxes obtained from different SPNDs. The reliability of the system in terms of *absolute* flux determination will be analysed later on, when activation dosimeter results will become available.

For next year we plan to irradiate DOLMEN in BR2 channels with higher fluxes and harder spectra, to extend the validation of the calculation models and to obtain more critical information on the detector burn-up. In a parallel irradiation program (FICTIONS) we will compare the behaviour of SPND's and sub miniature fission chambers in terms of the absolute value of the neutron and the gamma sensitivity and of the long-term sensitivity evolution (in collaboration with CEA - DER/SSAE/LSMN).

Based on the needs of other projects (fuel research, corrosion research, pressure vessel steel projects...), we will continue to improve and innovate the in-pile instrumentation.



Results for the 11 SPND's in DOLMEN during the BR2 cycle 05/2000: conventional thermal neutron fluxes obtained from the observed detector currents combined with the calculated detector sensitivities vs. the calculated relative neutron flux at the detector positions.

Development of data acquisition systems

The BR2 integrated data acquisition system for survey and experiments (BIDASSE) has been further upgraded. The system is designed to follow all operation parameters and is also used for experiments.

The BIDASSE system has its own fully independent network, which is running with Novell Netware and has its own dedicated server (the BIDASSE server).

One PC is used to make a bridge between the BIDASSE network and the SCK•CEN network. This PC sends a copy of updated information once a second to a server of the SCK•CEN network. In this way the SCK•CEN network is only seen by BIDASSE as one user.

All data acquisition units are based on PCs and are connected via coaxial connections to the BIDASSE server. The acquisition systems are passive and perfectly isolated from the instrumentation wiring. More than 700 analogue and 1100 digital inputs are presently available in real time.

Each data acquisition unit can be considered as one user of the BIDASSE system who regularly updates the databases after each measurement. Due to the dispatching of the acquisition tasks on different physical locations, a synchronisation process is needed in order to build a 'real picture' from the different databases at each time. This synchronisation is achieved with the distribution of pulses coming from the DCF77 atomic clock.

Of the more than five hundred PCs connected to the global network, about fifty users have at present access to the information provided by the BIDASSE system.

The user interface allows analogue signals as well as logged events to be followed. The data can be viewed on screen in real time or exported in a format readable by most software packages for off-line treatment and analysis. Since 2000 a user interface for on-line graphics is also provided allowing real time trend graphs on 14 channels at a time.

In 2000 several experiments were connected to the BIDASSE system, in particular the CORONA and the DOLMEN experiments that are testing in-pile sensors.

The CALLISTO loop presently uses the BIDASSE system on a routine basis, including an event recorder with 384 channels connected and 180 high-resolution analogue signals with one storage per minute on each channel. Since the end 2000, on-line calculations directly give the physical data necessary for the operation of the loop.

Partners

-	Studsvik Instrument (Nyköping, Sweden)
CEA/DER/SSAE/ LSMN	Commissariat à l'Energie Atomique/Département d'Etudes des Réacteurs/Service de Systèmes d'Aide à l'Exploitation/Laboratoire des Systèmes de Mesures Nucléaires (Cadarache, France)
CEA/DRE/SIREN	Commissariat à l'Energie Atomique/Département des Réacteurs Expérimentaux/Service d'Irradiations en Réacteurs et d'Etudes Nucléaires (Saclay, France)
HRP	OECD Halden Reactor Project (Halden, Norway)
IAEA	International Atomic Energy Agency
MEPhI	Moscow Engineering & Physics Institute (Moscow, Russia)
RRC Kurchatov Institute	Russian Research Centre (Moscow, Russia)
UKAEA	United Kingdom Atomic Energy Agency

Scientific Output

Publication

E. Koonen, B. Coupé, "A New Data Acquisition System for the BR2 reactor", IGORR News, n°13, November 2000.

Presentations

B. Ponsard, "Mixed Core Management: Use of 93% and 72% enriched uranium in the BR2 Reactor", Fourth International Topical Meeting on Research Reactor Fuel Management (RRFM 2000), Colmar, France, March 19-21, 2000.

B. Ponsard, "Production of Radioisotopes in the BR2 High-Flux Reactor", Seventh IIS International Symposium on the Synthesis and Applications of Isotopes and Isotopically Labelled Compounds, Dresden, Germany, June 18-22, 2000.

B. Ponsard, "Production of Radioisotopes in the BR2 High-Flux Reactor", Symposium on Isotope Production and Applications in the New Century (PACIFICHEM 2000 Conference), Honolulu, Hawaii, USA, December 14-19, 2000.

B. Ponsard, contribution to the 2000 Update Report of the OECD Nuclear Energy Agency, "Beneficial Uses and Production of Isotopes".

A. Makarenko, T. Petrova, "BR2 reactor steady state and transient modelling", Fourth International Topical Meeting on Research Reactor Fuel Management (RRFM 2000), Colmar, France, March 19-21, 2000.

P. Jacquet, A. Verwimp, S. Wirix, "MTR fuel testing in BR2", Fourth International Topical Meeting on Research Reactor Fuel Management (RRFM 2000), Colmar, France, March 19-21, 2000.

B. Verboomen, Th. Aoust, A. Beeckmans de Westmeerbeeck, Ch. De Raedt, "Irradiation of navel MTR fuel plates in BR2", Fourth International Topical Meeting on Research Reactor Fuel Management (RRFM 2000), Colmar, France, March 19-21, 2000.

Report

V. Sobolev, Ch. De Raedt, E. Malambu, M. Weber, "Dependence of the Sensitivity of a Self-Powered Neutron Detector on the Radiation Spectra of the BR2 reactor", BLG Report BLG-836, March 8, 2000.