JP9950574

Session 11-1

Recent Advances in the Utilisation and the Irradiation Technology of the Refurbished BR2 Reactor

Jean DEKEYSER, Philippe BENOIT, Camiel DECLOEDT, Yvan POULEUR,
Alfons VERWIMP, Marcel WEBER[*1], Marc VANKEERBERGHEN[*2]
and Bernard PONSARD[*3]

[*1] Department of Reactor Experiments
E-mail:jdekeyse@sckcen.be
[*2] Department of Reactor Materials Research
[*3] BR2 Division

Belgian Nuclear Research Centre, SCK•CEN
Boeretang 200, B-2400 Mol, BELGIUM

ABSTRACT

Operation and utilisation of the materials testing reactor BR2 at the Belgian Nuclear Research Centre (SCK•CEN) has since its start in 1963 always followed closely the needs and developments of nuclear technology. In particular, a multitude of irradiation experiments have been carried out for most types of nuclear power reactors, existing or under design.

Since the early 1990s an increased focus was directed towards more specific irradiation testing needs for light water reactor fuels and materials, although other areas of utilisation continued as well (e.g. fusion reactor materials, safety research, ...), including also the growing activities of radioisotope production and silicon doping

An important milestone was the decision in 1994 to implement a comprehensive refurbishment programme for the BR2 reactor and plant installations. The scope of this programme comprised very substantial studies and hardware interventions, which have been completed in early 1997 within planning and budget.

Directly connected to this strategic decision for reactor refurbishment was the reinforcement of our efforts to requalify and upgrade the existing irradiation facilities and to develop advanced devices in BR2 to support emerging programmes in the following fields:

- LWR pressure vessel steel,
- LWR irradiation assisted stress corrosion cracking (IASCC),
- reliability and safety of high-burnup LWR fuel,
- fusion reactor materials and blanket components,
- fast neutron reactor fuels and actinide burning,
- extension and diversification of radioisotope production.

The paper highlights these advances in the areas of BR2 utilisation and the ongoing development activities for the required new generation of irradiations devices.

1. INTRODUCTION

Materials testing reactors still hold a central position in the R&D to support the efficiency, reliability and safety of the operating nuclear power plants and to foster the development of advanced reactors (fission type and fusion type reactors and even new systems like the ADS machine). Therefore, the Belgian MTR BR2, which is one of the most effective of its type, will continue to play a primary role in the field of nuclear energy and especially the light water reactors. In parallel the BR2 also contributes significantly to the medical and industrial applications of neutron irradiations.

Operation of BR2 was only interrupted twice in the periods 1979-80 and 1995-96 to implement programmed refurbishment tasks, including the replacement of the beryllium matrix (ageing by embrittlement), and to perform detailed safety and reliability assessments [1], [2]. The reactor is in operation again since April 1997 under the forthgoing license regime that implies a 5-years periodical safety review. In this paper we look to the recent operation of the BR2 after the second refurbishment shutdown and focus on the advances in the utilisation of the reactor and of the associated irradiation technology.

Given the context of the Belgian nuclear power plants, which are based on the pressurised water reactor (PWR) type, it is clear that in the recent years SCK•CEN and BR2 have been more and more involved in the R&D activities related to the PWR type, in particular those questions concerning ageing of reactor materials (pressure vessel, a.o.), fuel behaviour at high burnup, reliability and safety issues. Also the Belgian NPPs are pioneering the utilisation of MOX fuel, strongly supported by experimental investigations in the BR2. Therefore this paper discusses more deeply the role of BR2 and its dedicated irradiation facilities for the support of the light water reactors. Beside the existing and operational facilities, several new facility concepts are also under development for emerging research programmes.

2. BR2 FEATURES AND OPERATING CHARACTERISTICS

The BR2 design, shown in Fig. 1, is optimised to offer the following main features [3]:

- a core with a central vertical 200 mm diameter channel, with all its other 78 channels inclined to form a hyperboloïdal arrangement around it. This geometry combines compactness with easy access at the top and bottom covers, allowing complex irradiation devices to be inserted and withdrawn;
- a large number of experimental positions, including 4 peripheral 200 mm channels for big irradiation devices. Through-loop experiments can be installed through penetrations in the bottom cover of the vessel;
- a remarkable flexibility of utilisation: the reactor core configuration and operation mode are adapted to experimental requirements;
- irradiation conditions representative of those of various power reactor types;
- high neutron fluxes, both thermal and fast.

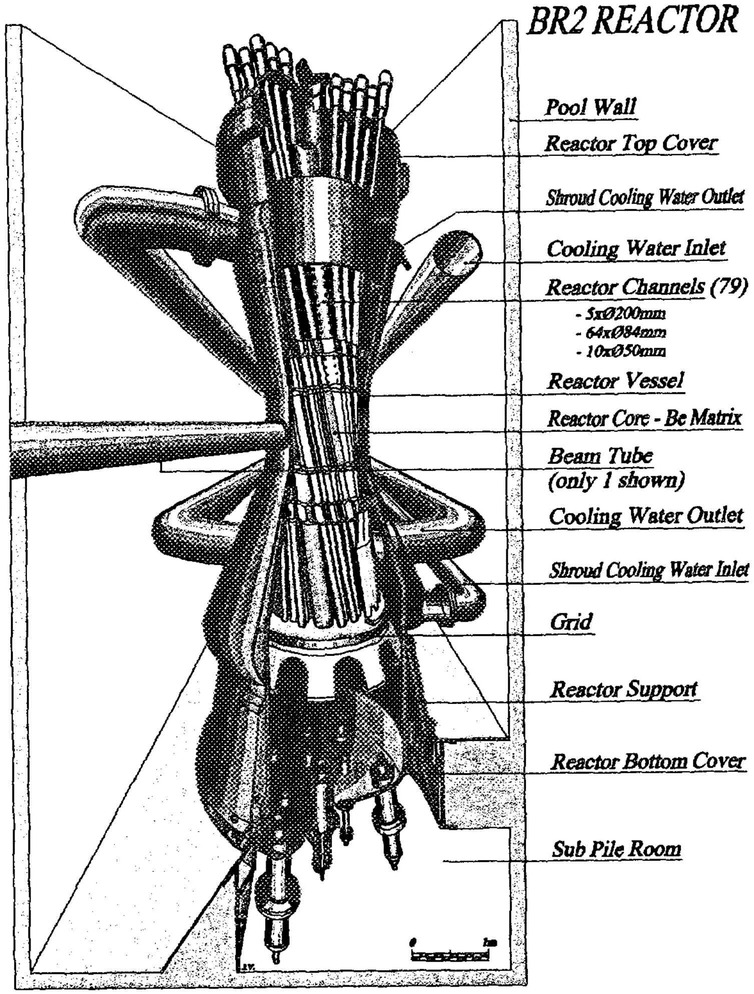
The principal technical data and operating characteristics of the reactor are shortlisted in Fig. 1. With regard to BR2's intrinsic safety aspects, the closed reactor vessel and primary cooling water circuit (pressurised at 12 bar) constitute an effective safety barrier for the in-pile devices and experiments. The air-tight containment building forms the ultimate safety barrier and is designed for the maximum hypothetical accident.

After the 1995-1996 refurbishment interruption, all these remarkable features and characteristics are again fully available with a high level of reliability and safety. This is already confirmed by the excellent experience during the recent two years of reactor operation [2].

3. OVERVIEW OF CURRENT IRRADIATION PROGRAMMES

3.1 Historical Survey

Since its early operation in 1963 until about 1989, the BR2 has been extensively used for fuel and materials testing related to the development of "new-generation" nuclear reactors, i.e. the gas cooled (CO_2 and He) thermal reactors, the liquid metal cooled fast breeder reactors (essentially for the SNR 300), the gas cooled fast breeder reactor, the testing of advanced LWR fuels and (to a lesser extent) the testing of fusion reactor materials. However most of the irradiation projects were devoted to the technological and safety problems of LMFBRs. Beside historical policies, this strategy was also strongly based on the excellent features of BR2 to achieve very high fast neutron fluxes (up to 7.10^{14}



BR2 : Technical Data

- Height of vessel : 10 m
- Core diameter : 1,1 m
- Core height (Be) : 0,9 m
- Reactor channels : total 79
    - 5 x Ø 200 mm
    - 64 x Ø 84 mm
    - 10 x Ø 50 mm
- Primary water pressure : 12 bar
- Primary water temperature : 45°C
- Construction materials :
    - Vessel : Aluminium
    - Covers : Stainless steel
    - Channels : Stainless steel & Beryllium
    - Inlet / Outlet pipes : Aluminium

BR2 : Operating Characteristics

- Reactor power
    - Nominal : 50 - 80 MW
    - Max. achieved : 106 MW
- Neutron fluxes *
    - Thermal : 1×10^{15} n/cm^2.s
    - Fast E > 0,1 MeV : 7×10^{14} n/cm^2.s
    - Fast E > 1 MeV : $3,5 \times 10^{14}$ n/cm^2.s

* Maximum values for heat flux of 470 W/cm^2 on reactor fuel elements

Figure 1. BR2 Reactor Design Features

n/cm².s above 0,1 MeV), to have large experimental volumes (up to ø 200 mm), to easily allow neutron spectrum tailoring and to adapt the operating modes to the experimental requirements.

This quarter of a century period saw a tremendous diversity of dedicated irradiation rigs and forced sodium cooling loops, including complex safety experiments with cooling blockages inside fast reactor fuel bundles and post-accident heat removal experiments on LMFBR core debris beds.

In parallel to these scientific and technological irradiations, the BR2 was also (and still is) heavily used for the production of different radioisotopes for medical and industrial applications.

A Belgian policy decision has ended all R&D efforts on fast neutron reactors in 1989. This caused a drastic strategic turn-around in the utilisation of BR2, resulting in renewed focuses on the development of different types of LWR fuels and materials, on LWR safety research and on fusion reactor materials. The isotope business was also extended and the production of neutron doped silicon was introduced.

3.2 Light Water Reactor Fuels

For many years SCK•CEN has been involved in different international and bilateral programmes on LWR fuel behaviour and development, both for PWRs and BWRs [4]. Irradiations in BR2 address stationary as well as transient regimes, while comprehensive post-irradiation examinations are conducted in the Laboratories for High and Medium Activity. The tested fuels concern mainly UO_2, MOX, fuel with burnable poisons (e.g. Gd_2O_3) and fuels with advanced cladding. Both fresh and pre-irradiated rods are tested, the latter retrieved from the previous BR3 reactor (PWR type) at the SCK•CEN site and from commercial power reactors.

A strong emphasis is increasingly given to the scientific modelling of fuel behaviour (and not just neutron irradiation), in particular the issues of fission gas release and thermal conductivity at high fuel burnup.

Dedicated facilities were designed and installed in BR2 for the LWR fuel experiments and are still fully operational. The main facilities are:

- CALLISTO-PWR loop
- Pressurised Water Capsules (PWC)
- Calibration and Cycling Devices (CCD) with ^{3}He screen.

(a) CALLISTO Loop.

The CALLISTO facility (CApability for Light Water Irradiation in Steady state and Transient Operation) is a specialised high pressure loop offering a comprehensive range of experimental conditions representative of PWR power reactors. Its basic layout allows to irradiate clusters of nine fuel rods (fresh or pre-irradiated) in each of the three in-pile sections, thus total of 27 rods [5]. Normally the rods are about 1 m long, but variants are possible. Each in-pile section could also accommodate three full length PWR rods, i.e. over 4 m long.

Up to now, fuel rods were irradiated in CALLISTO in nominal steady state regime in order to achieve their target burnup. However the loop can also be operated, within certain limits, in off-normal and transient regimes, e.g. power ramping or cycling, cooling mismatch conditions, loss of flow.

(b) PWC/CCD Devices.

The PWC rigs are versatile capsules with pressurised stagnant water in either PWR or BWR conditions. In its present layout a PWC in-pile section can receive one single fuel rod (fresh or pre-irradiated) of about 1 m length, or shorter segments (typically 30 cm fissile stack) which may be instrumented with central thermocouple and/or other scientific sensoring devices [6]. As shown in Fig. 2 (in-core part only), a PWC rig is surrounded by a CCD device, that incorporates a ^{3}He screen to perform power cycling or transients. The CCD is also instrumented to achieve precise thermal balance measurements on the fuel rod heating rate.

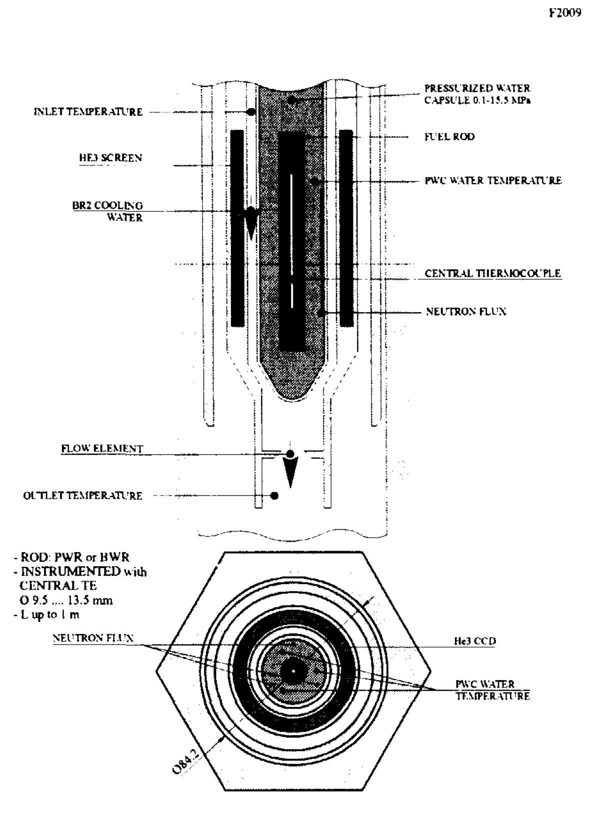


Figure 2. PWC-CCD Irradiation Rig

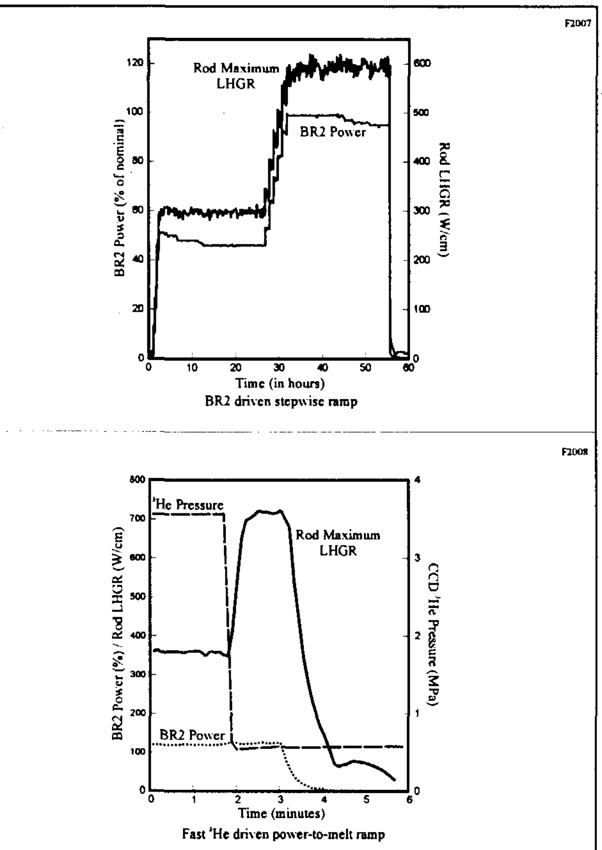


Figure 3. Typical Power Transients

Many different profiles of power transients, regarding amplitude, ramp rate and holding time, have been realised in the PWC/CCD devices, including power-to-melt tests. Some of these were achieved by ramping the power of the reactor also, to complement the capacity of the ^{3}He screen, as illustrated in Fig. 3.

An extrapolated design of PWC is feasible to accept 4 m long fuel rods, which could previously be irradiated in a commercial PWR.

3.3 Light Water Reactor Materials

All kinds of materials can be tested in BR2 up to very high neutron doses (thermal and/or fast). Current and planned programmes mainly concern the following:

- reactor pressure vessel steel: ageing behaviour and investigation of the embrittlement mechanisms
- reactor internal structural materials: especially the degradation phenomena of irradiation assisted stress corrosion cracking (IASCC).

Dedicated rigs have been engineered to irradiate test samples in different environmental and physical conditions, assuring scientific relevance as well as effectiveness and economy: open baskets (cooling of the samples directly by the BR2 primary water), VESTAL rig (specialised device to irradiate vessel steel samples in inert gas at about 290°C) and also the CALLISTO in-pile sections (with the samples immersed in PWR type loop water with representative chemistry). The latter option demonstrates the versatility of the CALLISTO design, which is presently applied for two R&D projects: CHIVAS (for RPVS testing) [7] and CORIOLIS (for IASCC testing).

3.4 Other Technological Programmes

We briefly mention here the neutron irradiation testing to support the development of Fusion reactors (TOKAMAK type) and the performant application of gamma irradiations for several types of targets.

(a) Fusion Reactor Materials.

Typical examples of fusion reactor materials which are currently irradiated in BR2 are given hereunder.

- *Structural materials:* these concern first wall materials (mainly different grades of stainless steels), divertor materials (e.g. molybdenum and copper alloys) and blanket materials (e.g. beryllium and tritium breeding components). The test samples are irradiated under representative neutron spectrum (in particular very high fast neutron flux) and to the required fluences and dpa-damage doses.
- *Tele-operation parts and components:* these concern the remote handling machines (inside the fusion reactor torus and near the first wall) which need to be tested and qualified under intense gamma ray fluxes. In this category we find electronic parts, robotic components, vision systems, optical fibres, approximity sensors and instrumentation sensors.

(b) Gamma Irradiations.

Dedicated gamma irradiation facilities are operational in the BR2 complex, using the gamma fluxes from either spent reactor fuel elements or from intensive ^{60}Co sources. Typical gamma dose rates are in the range of 3 to 30 kGy/h. The useful geometries available for the samples have diameters up to 270 mm and heights up to 900 mm. Irradiations are performed in controlled gas atmosphere and the samples can be tested at different temperatures up to 250°C if needed. These facilities are used for testing technical materials and components that need to resist high gamma doses, such as the tele-operation equipment mentioned above.

3.5 Radioisotopes and Si doping

Beside the scientific and technological experiments, the BR2 reactor has always been thoroughly used for the production of radioisotopes for medical and industrial applications [8] and, more recently, also for neutron transmutation doping of silicon to be used by the semi-conductor industry. The radioisotopes are produced in dedicated irradiation devices - in which the encapsulated target material can be loaded to and from the reactor whilst it is at power - and in irradiation baskets loaded into the reflector channels or inside fuel elements for a whole cycle irradiation. The main radioisotopes produced in the BR2 reactor are Mo-99 (Tc-99m), I-131, Xe-133, Ir-192, Sr-89, Re-186, Sm-153, Y-90, P-32, Co-60, Sn-117m, Yb-169, W-188 (Re-188), ...

Productions of Ir-192 and Sr-89 are performed in the central 200 mm Ø channel (maximum thermal neutron flux of 1.10^{15} $n.cm^{-2}.s^{-1}$) where seven irradiation positions can receive each one basket with 10 irradiation capsules. Specific activities of ≥ 700 Ci/g and ≥ 250 mCi/g respectively for Ir-192 and Sr-89 are obtained after irradiation of one cycle (21 days).

Mo-99 is produced at BR2 by irradiation of highly enriched targets (4 g U235) during 150 hours in a thermal neutron flux of $2{,}5\,10^{14}$ $n.cm^{-2}.s^{-1}$ inside the standard irradiation devices PRF (9 targets) and DGR1/2 (3 targets each). Activities of 150 Ci are obtained for each target at calibration time (180 hours after the end of irradiation).

Low specific activity Co60 was formerly produced by irradiation in the reflector. High specific activity Co-60 (≥ 300 Ci/g) is produced by irradiation of 175 g Cobalt capsules placed under the six control rods of the BR2 core.

Neutron transmutation doping (N.T.D.) of silicon ingots -up to 5 inches diameter, batch length up to 800 mm- is performed in the SIDONIE rig. This rig produces NTD silicon of high quality with a short turn-around time for the customer. High quality means that the target resistivity is met within 2 % axially and radially.

4. NEW FACILITY CONCEPTS FOR EMERGING PROGRAMMES

To cope with new emerging needs of the nuclear industry and the R&D community, and indeed to respond to actual specific requests, SCK•CEN is putting considerable efforts to maintain and develop its irradiation technology and its experimental facilities for BR2. The main programmes concerned are in the field of LWR materials, fuels, safety, fusion reactor materials and components, fast neutron reactor fuels for minor actinides transmutation, MTR development and radioisotopes production.

A brief outline on these different developments is reported hereafter. Probably not all of these facilities will actually be realised, but a high-flux versatile MTR like BR2 must assure an adequate degree of preparedness for the future needs.

4.1 Pool side facility for RPVS irradiation (MERLIN)

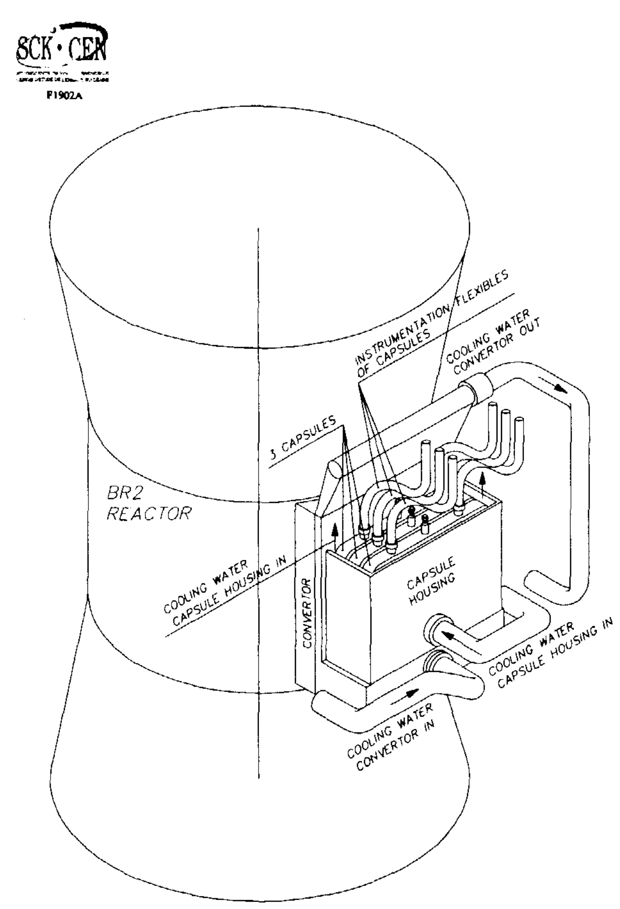


FIGURE 4. ISOMETRIC VIEW OF MERLIN POOL SIDE FACILITY

An important development work has already been put in the new irradiation facility MERLIN (Materials Experimental Research Facility for Large Irradiation volumes of Nuclear steel samples). This dedicated facility is to be placed in the water pool of BR2, tangent to the outer wall of the reactor vessel at its core region (Fig.4). It aims at irradiating large amounts of steel samples that are to be analysed in the framework of LWR pressure vessel embrittlement research programmes. The rig is mainly composed of three irradiation capsules with flat box geometry, containing the steel specimens, and a special neutron converter fuel element, that will transform the outflow of the reactor thermal neutrons into the required fast flux. It should be noted that the neutron flux levels present inside the reactor core are too high for most of the research programmes on LWR pressure vessel steels.

The design requirements of MERLIN fulfil the strict specifications for RPVS irradiation, mainly the following:

- fast neutron flux (E>1MeV) in the range of 10^{12} to $1{,}3.10^{13}$ n.cm^{-2}.s^{-1},
- typical fast neutron fluence: 4 to 5.10^{19} n.cm^{-2},
- specimen temperature in the range of 280 to 300°C,
- internal temperature gradient in each individual sample to be limited to 5K,
- inert gas environment,
- available test volume: up to 900 Charpy or 60 1T-cT specimens.

The limited internal temperature gradient implies to restrict the local gamma heating to less than 1 W/g, while the specified operating temperature requires a well-balanced electrical heating support over each of the three capsules. With regard to the neutron converter its design has been optimized so as to yield the required fast neutron flux levels in the specimens and a flat spatial flux profile over each of the capsule boxes [9].

At present the decision to actually construct MERLIN is pending on sufficient demands for irradiation testing of large quantities of RPVS specimens, so that the expected turnover, as well as the scientific output, can justify the initial investment of this facility.

4.2 Dedicated PWR loop for IASCC experiments (ECLIPS)

Within the framework of studies on irradiation assisted stress corrosion cracking (IASCC) for the core internals of BWRs, PWRs and even fusion reactors, realistic testing of material specimens under irradiation is required, characterised by a high fast neutron flux, variable water chemistry, adaptive loading and on-line monitoring. For that purpose a high pressure high temperature in-pile loop at the BR2 reactor is being designed: ECLIPS (Experimental Corrosion Loop for In-Pile Studies) [10]. Typical material tests will be performed in this vehicle, such as accelerated base irradiations at high fast neutron flux (up to 2.10^{14}n.cm^{-2}.s^{-1}), instrumented crack initiation and crack propagation testing, creep and relaxation testing and operational testing of in-pile sensors.

Fig. 5 shows the outline of the in-pile section (IPS) in its present design stage. The in-core part is positioned in the central hole of a BR2 fuel element (5-plates type) so as to achieve the required fast neutron flux. The pressurized water is contained within a double walled vessel and flows along a concentric pattern: upwards through the test sections and downwards through a surrounding annular channel. Inside the IPS the water is heated up to the specified test temperature by means of a recuperative heat exchanger, several electrical heaters and the nuclear heating.

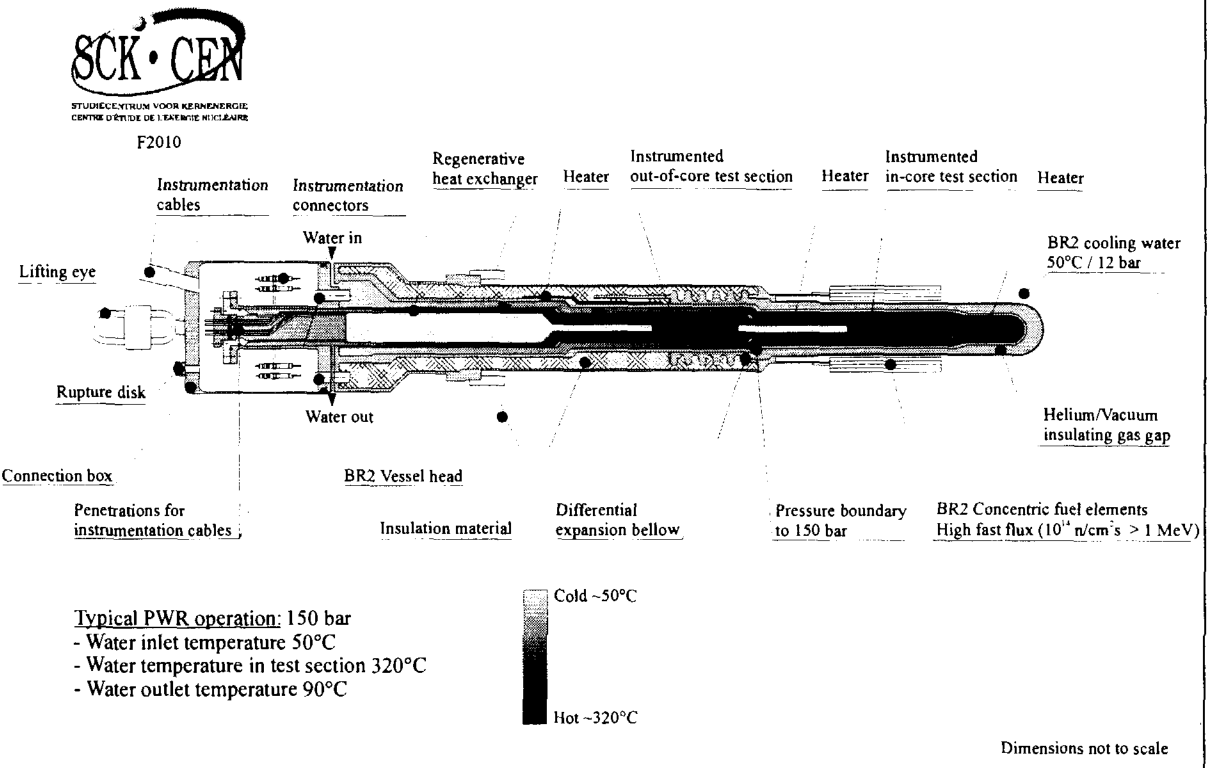


Figure 5. In-pile section of ECLIPS (Experimental Corrosion Loop for In-Pile Studies)

There are two test sections with specimens in the IPS: one in-core (i.e. the irradiated section) and one out-of-core. The same water (and thus the same water temperature and chemistry) flows through both tests sections, allowing to discriminate the effects of neutron irradiation on the experimental specimens. Beside the instrumentation needed for control of the loop operation (temperature, pressure, flow rate, ...), both test sections are provided with their experimental instrumentation, such as:

- self-powered neutron detectors for the thermal neutron flux,
- fast neutron fluence using activation dosimeters,
- detection of crack initiation using electrochemical noise analysis (in development),
- crack growth measurement using the potential drop technique.

In-pile water chemistry sensors are also foreseen (O_2, H_2, pH, conductivity).

The out-of-pile equipment of the ECLIPS facility contains the main circulating loop, which delivers the water flow to the IPS after purification and pressurisation, the secondary loop with different auxiliary equipment (water chemistry monitoring systems, make-up vessels, chemical conditioning, water sampling) and the gas supply system.

The ECLIPS facility is currently being developed in the framework of a scientific programme on nuclear corrosion at SCK•CEN and will be operated in collaboration with international scientific and industrial partners.

4.3 Rigs for other technological programmes

(a) Advanced PWC rig for LWR fuel

The PWC type of rig, briefly described above, is a rather simple and safe device to perform transient testing of a single fuel rod, in so far as the integrity of the rod is not lost during the irradiation compaign. However, in case of fuel clad rupture, the capsule water will be heavily contaminated by fission products and possibly also fuel fragments. This would require much time-consuming work to recover the defect fuel rod and to decontaminate and clean the in-pile section (pending if such is at all possible).

Therefore an advanced PWC design is being studied that would routinely allow to test fuel rods up to clad rupture and even to continue the irradiation after such event. This rig concept, called COSAC (Contamination **O**peration **SA**fety **C**apsule), will also enhance the natural convection circulation of the cooling water along the fuel rod, using a jet pump injection device, and improve the precision in the determination of the water temperature profile along the rod. Much attention is also paid to the layout of the rig with respect to integrating a more extended and advanced instrumentation, mounted unto and around the fuel rod (e.g. central temperature and cladding surface temperature, rod elongation, diameter variation, ...).

(b) In-pile loops for LWR fuel safety tests

In order to respond to future safety oriented needs, advanced water-cooled high pressure-high temperature loops are being studied, in particular:

- DESTIN: a large integrated loop which could accommodate up to 25 fuel rods, to be loaded in the central 200 mm flux trap of BR2;
- LILIPUT: a small integrated loop for a single fuel rod, to be loaded in one of the in-pile sections of the CALLISTO loop.

These loops are designed to perform experiments under realistic PWR conditions as to neutronics, thermohydraulics, water chemistry, etc.... They could be used for steady-state irradiations as well as for transient tests on either fresh or pre-irradiated fuel rods. Simulation of accidental control-rod withdrawal, of LOCA accidents and of fuel bundle degradation after severe accidents are among the possibilities. These new devices have been described in previous publications [11], [12].

(c) Testing of Fusion reactor blanket modules

Within the framework of the European Fusion programme, the development of breeder blanket systems requires also their realistic testing under irradiation in a fission MTR. SCK•CEN has already performed feasibility studies for such tests in BR2 on two types of blanket modules:

- helium cooled solid blanket (HCPB): Li-ceramic pebbles as breeder material and beryllium pebbles as neutron multiplier;

- water cooled lead-lithium blanket (WCLL): liquid Pb-Li as breeder material and pressurized water cooling.

Presently the design of different experiments for the WCLL blanket type is going on with regard to the behaviour of double walled cooling tubes, tritium permeation barriers and including an integrated experiment.

(d) Qualification of modern MTR fuel elements

Different new materials testing reactors and research reactors which are currently under design and/or construction require the development of dedicated fuel elements (either HEU or LEU) to fulfil in an optimal way the objectives of these reactors. As part of the license process, such fuel must also be tested and qualified under the specified operating conditions. BR2 is particularly well suited to perform such qualification tests because it operates itself with typical MTR fuel elements and it can submit the test fuel plates to very high neutron fluxes with a realistic MTR energy spectrum. So the designed operating range of the test fuel can easily be met in BR2, not only with respect to the neutronics but also the thermal and hydraulic characteristics. Regarding the potential risks of life-testing new fuels in BR2, the existence of the closed pressure vessel as a first safety barrier, in case of fission product release, is also a major advantage of BR2.

Studies for irradiation of fuel plates for several new MTR's are now on the way.

(e) Sodium loop for Pu burning and MA transmutation

Among other new devices which could be operated in BR2 is an integrated sodium-cooled loop for testing plutonium-enriched fuel rods and minor actinides loaded fuel rods under fast neutron reactor conditions. These experiments are aimed to investigate the accelerated burning of plutonium and the transmutation of minor actinides, as a possible scenario for the back end of the fuel cycle. Obviously BR2 has achieved a long-standing and successful expertise in the technology of in-pile sodium loops. No wonder that more recent scooping studies have indicated the excellent feasibility to perform such transmutation experiments.

5. CONCLUSION

The extensive refurbishment programme of the BR2 reactor has been successfully accomplished within the planning in the period 1995-1996, leading to restarting reactor operation in April 1997.

In parallel, SCK•CEN reinforced its efforts to requalify and upgrade the existing irradiation facilities and to develop advanced devices at BR2 in support of different emerging programmes. These efforts are mostly dedicated to the fields of LWR fuels and materials, although covering also many other fields like reactor core safety and fusion reactor materials.

In this way the BR2 remains well prepared to cope with opportunities and challenges for scientific irradiations and radioisotope productions, well into the next century.

6. REFERENCES

[1] J-M. Baugnet, "Restart of a Refurbished BR2", Nuclear Engineering International, November 1997, 41.

[2] P. Gubel, J. Dekeyser, J. Van der Auwera, "The BR2 Refurbishment Programme: Achievements and Two Years Operation Experience Feedback", ASRR VI, Mito, Japan, 29-31 March, 1999.

[3] SCK•CEN brochure, "BR2 Multipurpose Materials Testing Reactor - Reactor Performance and Irradiation Experience", November 1992.

[4] Y. Vanderborck, J. Basselier, J. Dekeyser, S. Bodart, "Fuel Material Irradiation Programmes", BELGATOM 2nd International Conference, Brussels, Belgium, 21-24 May, 1995, Transactions, session 6-5.

[5] P. Benoit et al., "CALLISTO: a PWR in BR2 - Design, Construction and Licensing", International Conference on Irradiation Technology, Saclay, France, 20-22 May, 1992.

[6] S. Bodart, C. De Raedt, B. Ponsard, "Single LWR Fuel Rod Irradiations with Power Transients in BR2", International Conference on Irradiation Technology, Saclay, France, 20-22 May, 1992.

[7] A. Fabry et al., "BR2 Irradiations in Support of Enhanced Surveillance of Nuclear Reactor Pressure Vessels", ENS Class 1 Topical Meeting on Research Facilities for the Future of Nuclear Energy, Brussels, Belgium, 4-6 June, 1996, Proceedings, 395-405.

[8] B. Ponsard, J-M. Baugnet, "Le Rôle de BR2 dans les Applications Non Energétiques du Nucléaire", Conférence sur le Programme COMETT, Liège, Belgium, 25 October, 1994.

[9] Y. Pouleur et al., "Optimization of a Fuel Converter for the MERLIN Materials Testing Facility", 2nd Int. Topical Meeting on Research Reactor Fuel Management, Bruges, Belgium, 29-31 March, 1998, Transactions, 26-30.

[10] M. Wéber, M. Vankeerberghen, F. Moons, "ECLIPS: a Dedicated Facility for Irradiation Assisted Corrosion Studies", 1998 JAIF Int. Conf. on Water Chemistry in Nuclear Power Plants, Kashiwazaki, Japan, 13-16 October, 1998, Proceedings, 335-342.

[11] P. Gubel, J. Dekeyser, E. Koonen, P. Benoit, A. Verwimp, "The Refurbishment of the Belgian MTR BR2 and its Future Utilization", ASRR V, Taejon, Korea, 29-31 May, 1996, Proceedings Vol. 1, 69-76.

[12] P. Benoit, "DESTIN - An Integrated PWR Loop for the Destructive Testing of Fuel Bundles", ENS Class 1 Topical Meeting on Research Facilities for the Future of Nuclear Energy, Brussels, Belgium, 4-6 June, 1996, Proceedings, 213-222.