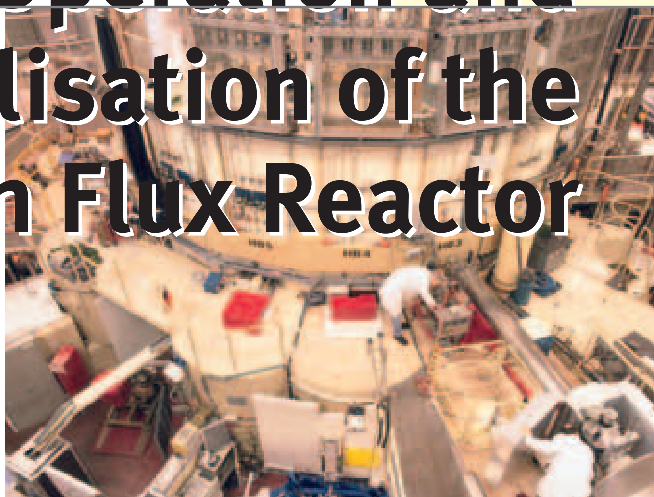
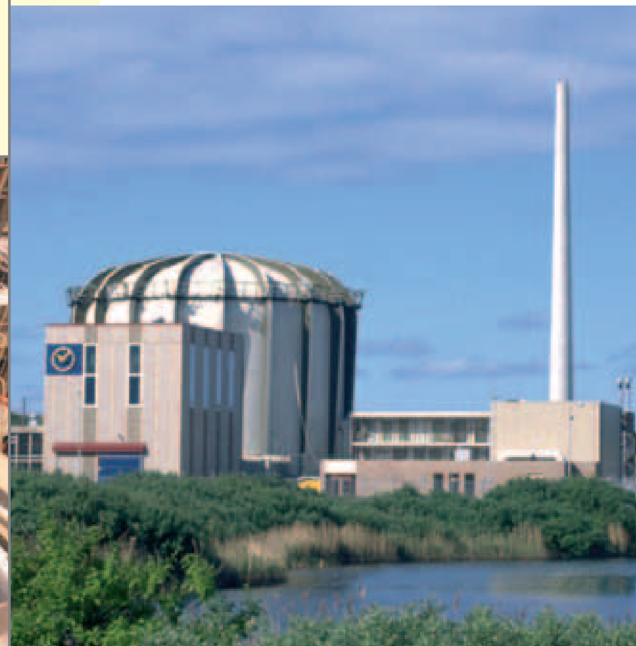
Operation and Utilisation of the High Flux Reactor





Annual Report 2002

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Institute for Energy

EUR 20773 EN

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Foreword

The current supplementary programme of the High Flux Reactor (HFR), financed by France, Germany and The Netherlands, is managed by the JRC and covers the period 2000-2003. The HFR, located in Petten, The Netherlands, is one of the most powerful multi-purpose research and test reactors in the world and today its operation has been entrusted to the Nuclear Research and consultancy Group (NRG). Having provided irradiation and post-irradiation examination services for decades, its mission was extended in recent years to medical support both through the production of radioisotopes and patient treatment at the Boron Neutron Capture Therapy Facility (BNCT). Today, the HFR is the European leader in terms of radioisotope production volume and one of the European pioneers in BNCT research activities.

In 2002, further to additional indications on weld anomalies discovered in the summer 2001 inspection, serious concerns were voiced about the safety of the plant. Accordingly, on 8 February 2002, in agreement with NRG and the Dutch nuclear safety authority, the "Kernfysische Dienst" (KFD), the European Commission decided to temporarily shut down the reactor. This shut-down period was used for an external safety culture review performed by an expert group of the International Atomic Energy Agency (IAEA), for the definition of an improvement action plan and for an external inspection of the welding anomaly observed during the 2001 inspection.

The IAEA review concluded that the reactor was in good condition and made recommendations and suggestions for further safety improvements. As a consequence, a programme on safety culture improvement was set-up. In addition, following the external inspection of the welding anomaly, a comprehensive plan for structural assessment was devised. These actions allowed the reactor to start again on 22 March and operations have continued normally since then. A new in-service inspection will take place before the end of the summer of 2003.

The shutdown raised major concerns for the continued supply of medical radioisotopes. The issue was raised during an emergency debate in the Dutch Parliament in February 2002 and re-emphasized this crucial aspect of HFR's role in our society.

The experimental activities were carried out as explained in this annual report.

At the time of writing this foreword, I am pleased to state that both the IAEA action plan on safety culture improvement and the plan for structural assessment are progressing as planned thanks to the efforts devoted since the events in February 2002.

Marc Becquet

September 2003

Introduction

The High Flux Reactor (HFR) Petten, managed by the Institute for Energy[1] (IE) of the JRC of the European Commission, is one of the most powerful multi-purpose materials testing reactors in the world.

The HFR is of the tank-in-pool type, light water cooled and moderated and operated at 45 MW. In operation since 1961, and following a new vessel replacement in 1984, the HFR has a technical life beyond the year 2015.

The reactor provides a variety of irradiation facilities and possibilities, *[1]*, *[2]*: in the reactor core, in the reflector region and in the poolside. Horizontal beam tubes are available for research with neutrons. Gamma irradiation facilities are also available. Excellently equipped hot cell laboratories, on the Petten site, can provide virtually all envisaged post-irradiation examinations.

The close co-operation between JRC and NRG[2] on all aspects of nuclear research and technology is essential to maintain the key position of the HFR amongst research reactors world-wide *[3][4][5]*. This co-operation has led to a unique HFR structure, in which both organisations are involved. JRC is the owner of the plant (in fact only for a lease of 99 years), the plant- and budget manager and the licence holder. JRC develops a platform around HFR as a tool for European collaborative programmes. NRG operates and maintains the plant, under contract, for JRC and manages, since the 2000/2003 programme, the commercial activities around the reactor.

Furthermore each organisation provides complementary possibilities around the reactor activities, such as the hot cell facilities of NRG or the experiment commissioning laboratory of JRC.

HFR is also in the core of the Medical Valley association. This association between IE, NRG, Tyco (Mallinckrodt Medical), Urenco and hospitals leads to a Centre of Excellence, unique in Europe.

A co-operation agreement for the use of HFR beam tubes was signed in 1999 between JRC, NRG and IRI Delft[3]. This agreement allows free access of the IRI teams to the HFR beam tubes and allows a fruitful collaboration in the technological improvement of the HFR beam tubes.

[1] Since 1st September 2001 the name Institute for Advanced Materials is changed to Institute for Energy (IE)
[2] Nuclear Research and consultancy Group (NRG) is a company (with 40 years of experience!) established in 1998 through the merger of the nuclear activities of ECN (The Netherlands Energy Research Foundation) and KEMA
[3] Interfaculty Reactor Institute, Delft University of Technology, Delft, The Netherlands

Highlights

HFR main figures

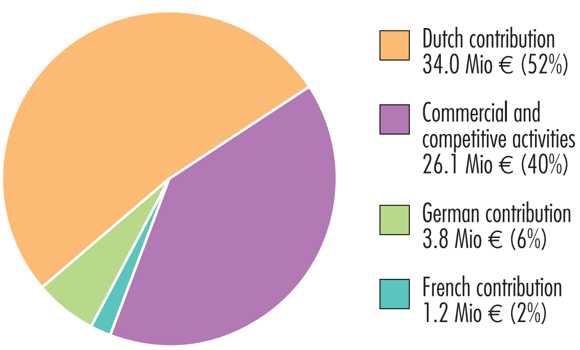
In 2002, the HFR was in operation during 275 days. This figure is to be compared with an original planning of 290 operation days before the reactor stop (see paragraph below) and a planning of 270.3 operation days further to the stop. Nominal power has been 45 MW with a total energy production of approximately 12383 MWd, corresponding to a fuel consumption of about 15.5-kg of U-235.

The HFR budget and split of activities is shown below.

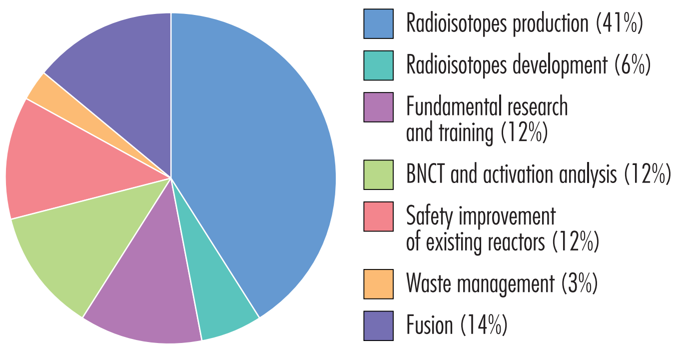
Fusion

HFR contributes to the fusion technology development by providing experimental results utilising the HFR as the neutron source and the hot cell laboratory to perform post-irradiation testing. The main areas of interest are the ITER vacuum vessel, the blanket development, and the development of the reduced activation materials: chromium steel and ceramic composites.

HFR budget



HFR activities



HFR operation, management

Following allegations related to safety and safety culture at the High Flux Reactor (HFR), the HFR underwent an enforced shut down for a full cycle and two reviews were carried out. Positive outcomes from both reviews as well as support statements from the Dutch Safety Authority and the Environment Minister led to a restart of the HFR on 22 March. IE has committed itself to full implementation of the recommendations and improvement suggestions in the reports.

As part of the continuous safety plan, the HFR holds every three years a large-scale simulation of a nuclear accident to test the operation of the emergency contingency plan for the Petten site. In 2002, one such exercise was held on 22 April. Over 150 people were involved, including the fire service, police, ambulance teams, special medical units, local hospitals, and even the army who set up and demonstrated a special decontamination facility. The exercise specifically aimed at testing communication and co-ordination between the different emergency services on-site and the crisis management team.





External relations

A technical co-operation agreement on safety is under discussion with HFR's two other "sister"-reactors: R2 (Sweden) and SAFARI (South Africa).

150 visits involving a total of 955 people were organized at the HFR. Guided tours in the HFR, held during the Petten Open Day event (19 October) as well as the attractiveness of JRC and Commission stands, and the computer activities specially designed for children, attracted many visitors and contributed greatly to the huge success of the day.

Mrs. A.-M. Jorritsma, Dutch Minister of Economic Affairs and Vice-Prime Minister of the Netherlands, visited the Institute on 8 April with representatives of the Dutch Directorate-General for Energy. During her visit the Minister discussed several energy-related topics with researchers from the Institute. On 11 October Mrs. G. Dicus, member of the US Nuclear Regulatory Commission (NRC), together with representatives from the US Embassy in Den Haag and from the US Delegation to the EU visited IE. In addition to discussions on adequate measures for the protection of public health and safety related to civil nuclear installations, a tour of a number of laboratories was organised.

Fission

In the frame of the Shared-Cost Action ADIMEW, a major campaign was successfully completed for 3-D mapping of residual stresses in a 51-mm thick dissimilar metal piping weld. The obtained results confirm the feasibility of such testing based on the LCNDF. These results will be used by major European industrial and academic organisations for the calibration of advanced numerical techniques for the prediction of such internal stresses.

On 27-28 March a workshop on irradiated stress corrosion cracking in reactor internals was organised in Petten by the Ageing Materials European Strategy (AMES) European Network. 25 participants agreed to the set-up of a dedicated European network.

In co-operation with the European Nuclear Society and the International Atomic Energy Agency (IAEA), IE hosted the highly successful 3-day HTR Conference from 22 to 24 April, which was attended by 185 participants from 18 countries, including China, USA, South Africa, Korea and the Russian Federation.

The NET European Network on Neutron Techniques Standardisation was launched on 23-24 May. 26 organisations attended the kick-off meeting. The scope of the network covers experimental and analytical studies, evolution of internal stresses and microstructure and defects due to welding and heat treatment.

Medical applications

The 2002 reactor stop highlighted the importance of HFR as a worldwide supplier of medical radioisotopes.
Treatment of the last patient in the current BNCT trial was finalised, bringing the total to 26 patients covering more than 100 treatment days. The outcome of the treatments so far has shown that there are no negative effects on tissues surrounding the cancer and that the expectancy and quality of life of the treated patients is at least as good as for conventional treatments.

The 10th International Congress on Neutron Capture Therapy (NCT) was co-organised by JRC-IE in Essen on 8-13 September. Almost 280 participants from around the world agreed on placing greater emphasis on the clinical aspects of BNCT. Also a pre-kick-off meeting for a European network on NCT was held, and collaboration between the Petten-Essen and Boston-MIT groups for parallel trials was confirmed.

HFR: The Reactor

HFR operation and related services

In 2002 the regular cycle pattern consisted of a scheduled number of 290 operation days and two maintenance periods of 19 and 24 days. In reality the HFR was in operation during 275 days (Figure 1). This corresponds to an actual availability of 94.7 % with reference to the original scheduled operation plan. Nominal power has been 45 MW with a total energy production of approximately 12383 MWd, corresponding to a fuel consumption of about 15.5-kg of U-235.

At the beginning of the reporting period, the HFR was in operation for the performance of cycle 01.12. Towards the end of the reporting period the reactivity measurements for the FLUX 2002 programme were performed. At the same time, the yearly HFR reactor training programme was carried out. Activities performed in the framework of the regular HFR operators' training took place immediately after the scheduled ends of cycles 02.07, 02.08, 02.09 and 02.10.

The operating characteristics for 2002 are given in Table 1. HFR cycle 02.02 (originally scheduled in the operation plan) was cancelled due to the IAEA safety culture audit and because of subsequent additional start-up conditions outlined

Table 1 **2002 operational characteristics**

			OPERATING TIME					SHUT-DOWN TIME				
Cycle Begin-End	HFR Cycle	Generated Energy	Planned	Low Power	Nominal Power	Other Use	Total	Planned	Unscheduled	Number of Interruptions		Stack Release (of Ar-41)
2002		MWd	hrs	h.min	h.min	h.min	h.min	h.min	h.min	PD	Scram	Bq x E+11
01.01-21.01	01.12	1047.59	496		496.00		496.00	08.00				6.0
22.01-18.02	02.01	1128.85	592	01.56	599.04		601.00	71.00				6.0
19.02-18.03	02.02		592	No reactor operation performed					672.00			
19.03-16.04	02.03	1123.52	592	01.42	598.53		600.35	80.00	14.25			7.0
17.04-29.04	Maintenance period							312.00				
30.04-27.05	02.04	1212.31	544	06.47	643.00		649.47	22.13				6.0
28.05-24.06	02.05	1126.94	592	02.04	599.46		601.50	70.10				6.0
25.06-22.07	02.06	1133.64	592	02.08	604.06		606.14	65.41	00.05		1	6.0
23.07-12.08	Maintenance period							504.00				
13.08-09.09	02.07	1126.22	592	02.02	600.28	00.28	602.58	68.57	00.05		1	6.0
10.09-07.10	02.08	1135.53	592	02.06	605.00	00.08	607.14	64.37	00.09		2	5.0
08.10-04.11	02.09	1107.37	592	01.58	589.52	05.13	597.03	75.52	00.05		1	5.0
05.11-02.12	02.10	1127.54	592	01.45	600.53	00.32	603.10	68.50				5.0
03.12-30.12	02.11	1113.93	592	02.12	590.48	31.49	624.49	47.11		2		14.0
31.12	03.01							24.00				
	TOTAL :	12383.44	6960	24.40	6527.50	38.10	6590.40	1482.31	686.49	2	5	72
Percentage of total time in 2002 (8760 h) :				0.28	74.52	0.43	75.24	16.92	7.84			
Percentage of planned operating time (6960 h) :				0.35	93.79	0.54	94.69					

PD: Power decrease

Figure 1 **HFR availability**

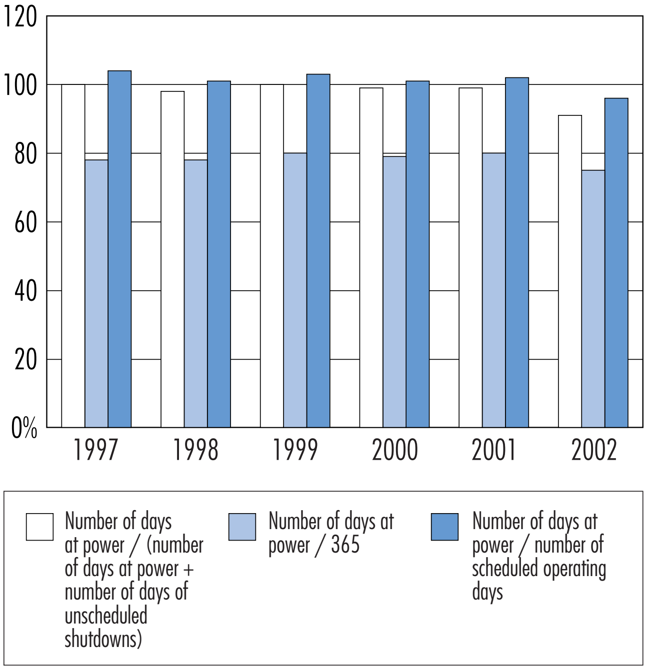
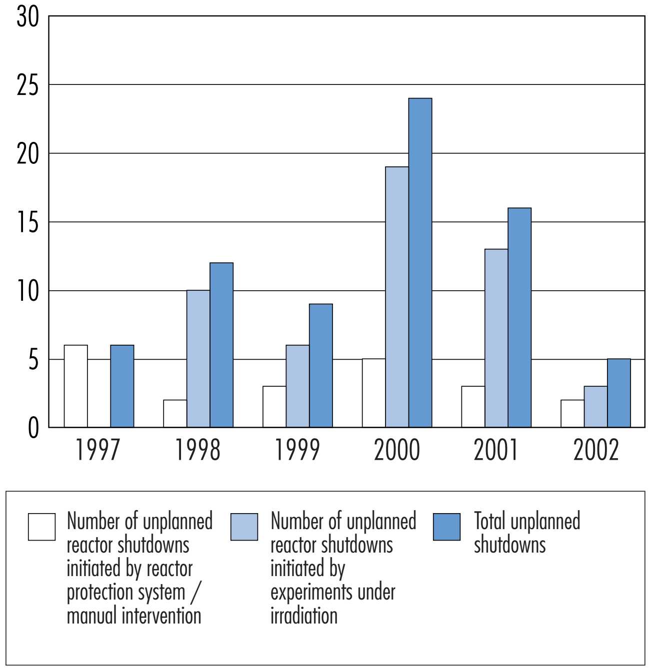


Figure 3 **HFR unscheduled shutdowns**



by the Dutch regulatory body as well as reactor vessel in-service inspection. Consequently, a part of the maintenance activities, which were planned for March 2002, was carried forward to this period. A new 2002 HFR cycle programme was then made consequently to this period of investigation, measurements and maintenance. Further, the start of cycle 02.09 was delayed by an additional inspection with respect to concrete ageing; this inspection was carried out by the Dutch regulatory body and external specialists.

With regard to the revised annual programme where 270.3 full power days were scheduled, the ratio of actual to scheduled availability rises to 100.6 %.

All details on power interruptions and power disturbance occurring in 2002 are provided in the figures above, showing that 5 scrams occurred, four of which were due to human intervention. This value is the lowest since 1997.

In 2002, 150 visits to the reactor, involving 955 people were organized. Alongside international colleagues and relations in the medical world, a number of people from the local community took advantage of the open day during each cycle to visit the facility.

Safety and Quality Management

INSARR (INtegrated Safety Assessment of Research Reactors) mission to the HFR

At the request of the European Commission, Joint Research Centre, Institute for Energy, the IAEA conducted an Integrated Safety Assessment of Research Reactors (INSARR) to the HFR in March 2002.

The terms of reference of the mission were defined in a preparatory mission; they covered elements of Safety Management and Safety Culture, Nuclear Safety, Licensing, Modifications, Quality Assurance and Emergency Planning.

A team of International Experts representing eight nationalities and having a good balance of operational and regulatory experience conducted the review. Among the various members were the responsible for Safety Culture and the Head of the Research Reactor Safety Unit from the IAEA.

Before the mission started, it was well-known that authorities, mass media and specialized publications in The Netherlands would pay substantial attention to several issues related to the safety of the HFR at Petten,given that:

- deficiencies were presumed in the Safety Culture,
- a welding joint in the reactor vessel was defect, and
- violations of safety precautions were alleged.

The mass media informed the IAEA of the above negative comments but also emphasised more positive aspects such as the HFR contribution in the field of radiopharmacy and in the treatment of brain tumours using BNCT.

IE/JRC, the HFR licence holder, in agreement with the Dutch Safety Authorities (KFD) decided as a precautionary measure, to shut down temporarily the HFR during a period that would include the week of the INSARR mission. Measures were taken to minimize the disruption of supply of medical radioisotopes and of treatment of cancer, whilst carrying out the measurements and improvements agreed upon with the Dutch safety authorities. Further, this shut-down would facilitate the participation of the operating group from NRG in the INSARR mission. The restart of the reactor was linked to the results of the INSARR mission, the results of the reassessment of the weld defect and the decision of the competent authorities. The purpose of the re-assessment was to check whether the defect had grown or changed in any way.

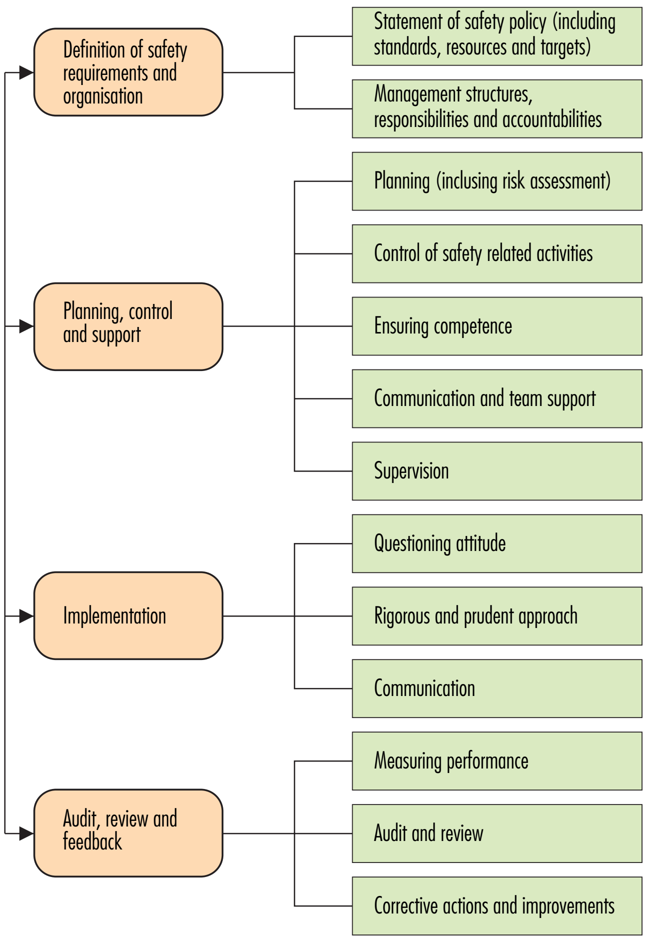
Objectives of the mission

- To perform an assessment of the safety management and safety culture, to establish to what extent the safety issues receive their due attention from all the organizations involved in the operation of the HFR.
- To verify that activities important to safety are managed, performed and evaluated in accordance with a suitable programme, safety policies and procedures to secure a safe operation of the reactor under all operational situations.
- The bases of the review are the IAEA standards and good international practices according to the agreed terms of reference. The purpose of the review was the identification of safety issues and the provision of associated recommendations or suggestions.

Review of safety management and safety culture

The review was based on the major components of a safety management system as defined in the IAEA INSAG-13 report:

"The safety management system comprises those arrangements made by the organization for the management of safety in order to promote a strong safety culture and achieve good safety performance". The major components of this system are illustrated in the figure below.



General findings

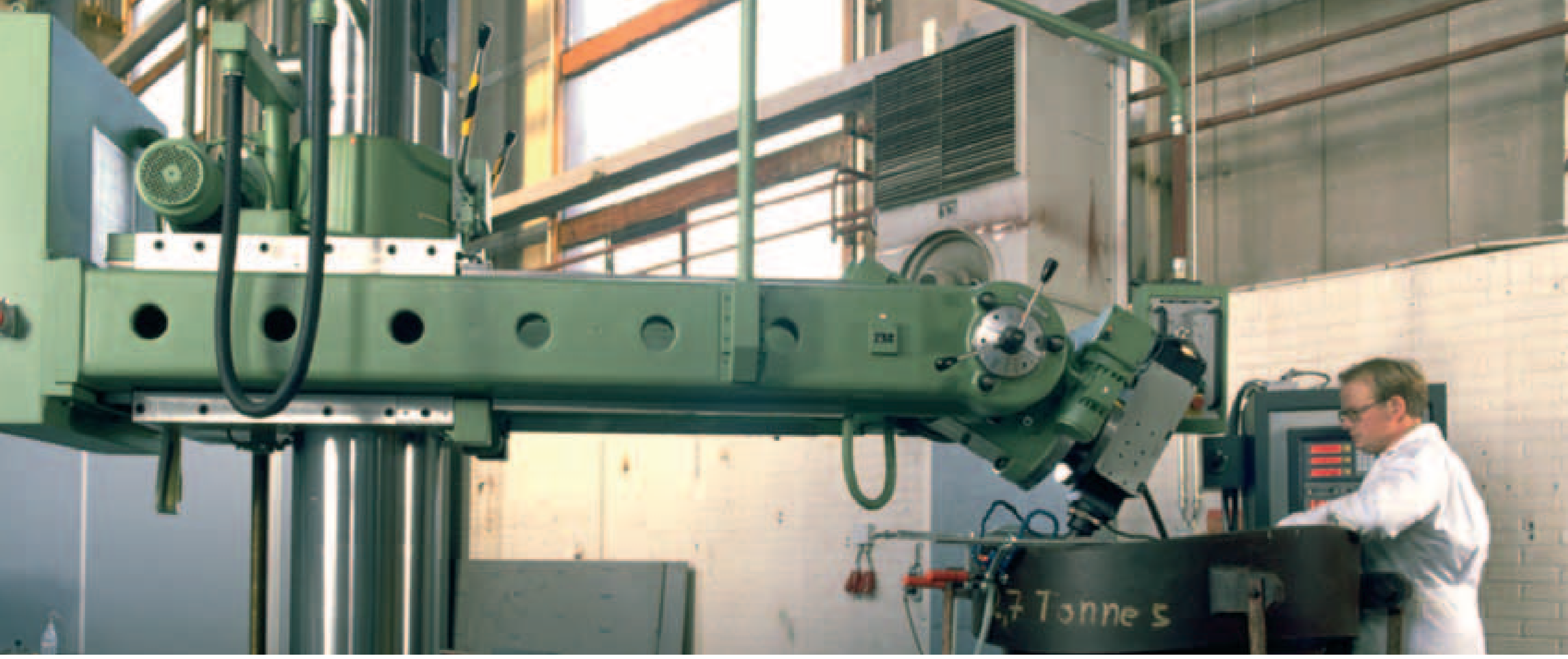
The organizations under review already possess features that would be helpful in any future effort to develop a good safety culture. Some of these features are listed below:

- Nuclear safety is recognized as important to the organizations.
- Technical competence is strong, providing the organizations with the capability to manage complex issues.
- People are dedicated and hardworking.
- Safety culture is recognized as fundamental to good safety performance.
- Many employees within the organizations are motivated to work safely and care for the safety of others who work with them.

During the review process there was excellent cooperation by people from all levels of the organizations. People were willing to provide all information requested and were open in their responses to questions. This suggests that the workforce is confident in its approach to issues and has a mature understanding of the aims of the review.

The recommendations and suggestions resulting from the INSARR mission formed the basis of a strategic improvement plan, prepared by JRC in close cooperation with NRG.

To guarantee a sustained improvement of the Safety Culture at the HFR, this plan was rolled out in a global list and elaborated into detailed sub-actions. The progress of the implementation is regularly assessed and the implementation will be completed by the end of 2003.

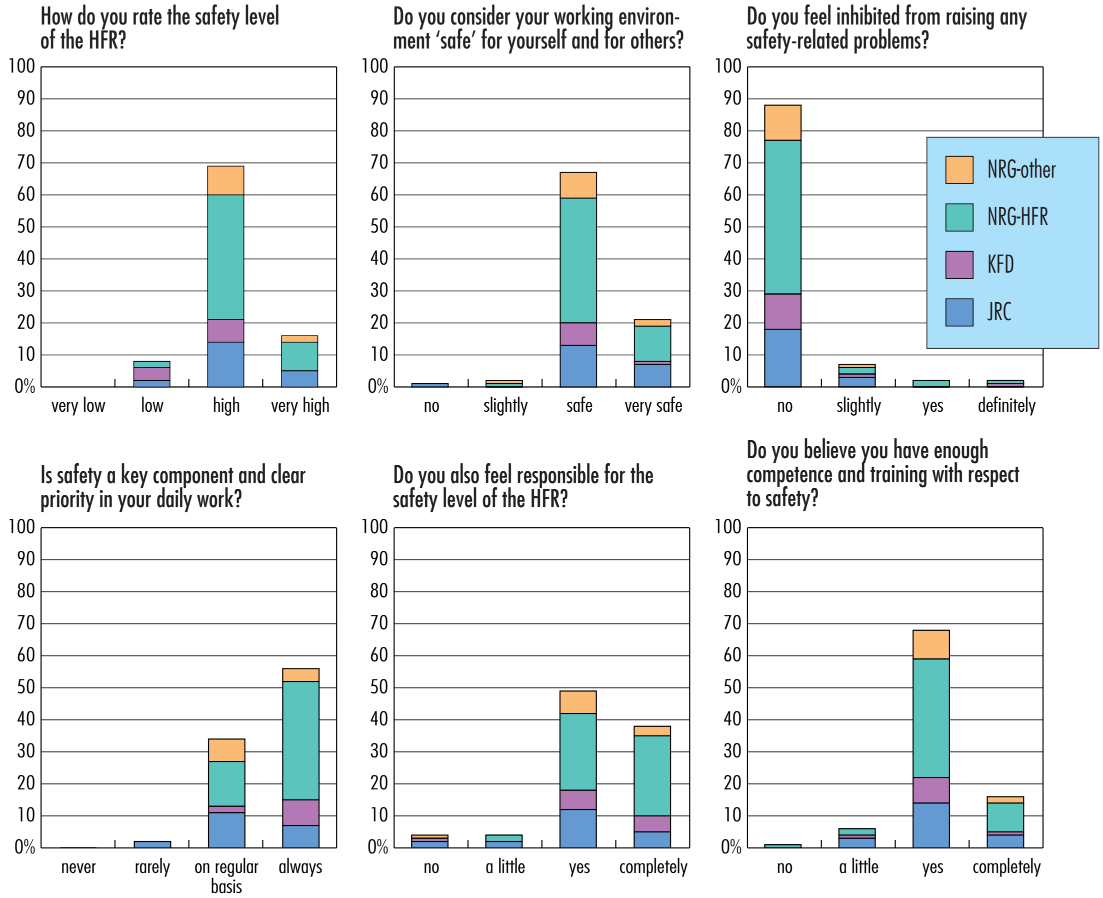


Survey on "your perception of HFR safety"

Self-assessment plays an important role in monitoring and enhancing the safety culture. As a preparatory step towards the HFR self-assessment, a dedicated Safety Culture Working Group issued a questionnaire which was sent to 139 employees of JRC, NRG and KFD, who are directly involved with HFR activities. The questionnaire was meant to sample a first base line of views and perceptions about safety in the HFR. Of the 139 questionnaires, 88% were returned by the four target groups:

- NRG-HFR, i.e. NRG employees working in the HFR
- NRG-other, i.e. other NRG employees with regular working contacts with the HFR
- JRC, i.e. JRC employees both directly involved in the HFR and with regular contacts
- KFD, i.e. all KFD staff.

The questionnaire consisted of 10 questions and the opportunity to provide suggestions concerning HFR safety. The results provided a general picture showing that the safety level of HFR was perceived to be high. Employees indicated that they knew to whom to go to with safety problems and that they did not feel obstructed to raise attention to safety issues. The overriding priority which safety should have in all activities is fully endorsed. Employees felt that they personally carried responsibility for safety and had the adequate knowledge to do so.



Fuel Cycle

Front end

In 1999, the decision was taken to convert the HFR to low enriched uranium (LEU) fuel. An exchange of diplomatic notes in January 2000 between the European Commission and the United States authorities ensued concerning the conversion to LEU and interim supply of high enriched uranium (HEU) from the US. As a result, an export licence was obtained from the US Nuclear Regulatory Commission allowing HEU supply from the US to fuel the HFR for a period of four years. Quantities authorised for the first two years have been delivered. Arrangements for the remaining supply were prepared.

During the year 2002 new fuel elements and new control rods were inspected at the manufacturer's site and delivered on schedule. A new order for manufacture and delivery of fuel elements and control rods was placed.

Further, a prototype LEU fuel element ordered in 2001, was manufactured, inspected and delivered successfully. Testing of this prototype element has meanwhile started.

Back end

Following successful shipments of HFR spent fuel in 2000 (COVRA, central organisation for radioactive waste in the Netherlands) and 2001 (US Department of Energy Savannah River site), further removal of spent fuel is under preparation to ensure continuation of HFR operation. Two shipments to COVRA are scheduled for 2003. A transport licence application has been made. The shipments will be performed with new MTR-2 containers, which were delivered in 2002. After shipment, the spent fuel containers will be temporarily stored at the COVRA site to await unloading and transfer of the spent fuel to the HABOG facility for long-term storage. The HABOG facility (Figure 4), presently under construction at the COVRA site, is scheduled to become available for storage of spent fuel and highly radioactive waste in the second half of the year 2003.

Figure 4 **HABOG facility under construction**

HFR: The Programmes

HFR as a Tool for European Programmes

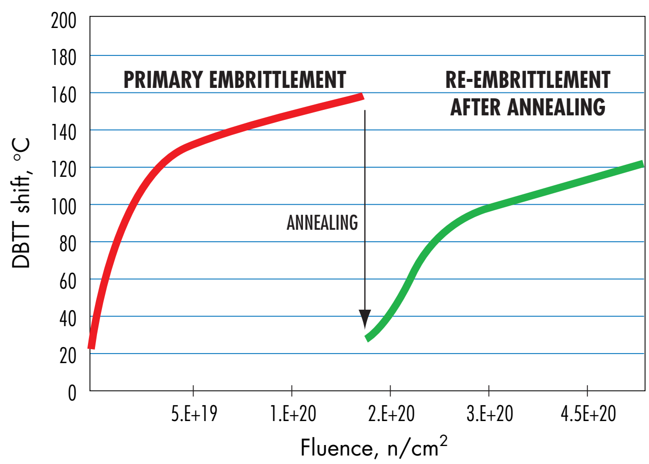
AMES

Executive summary & main results and achievements

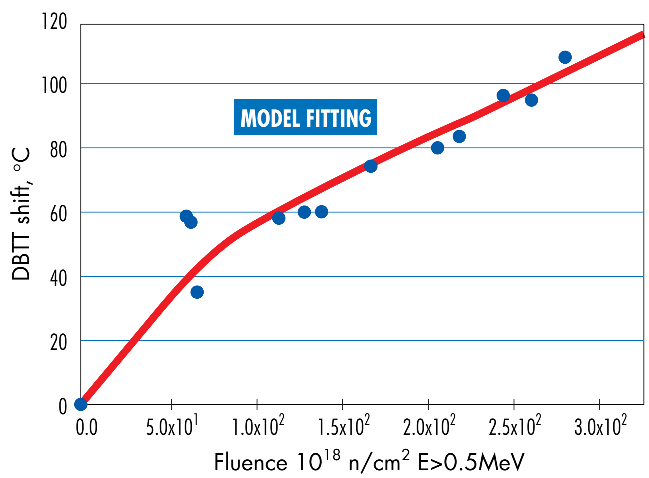
The Institutional Project AMES (Ageing Materials European Strategies) is the framework for activities aimed to understand, monitor, predict and mitigate the degradation of critical materials for plant life management of primary components in nuclear reactors. Western and eastern types of steels are involved in the various activities. The various activities are undertaken as international co-operation projects with key players in Western Europe, Accession Countries and NIS countries.

The main achievements are summarised in the following:

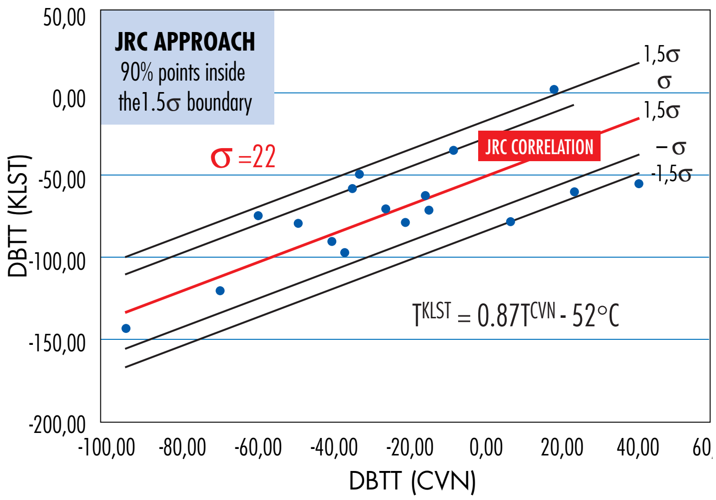
- Understanding the mechanism of irradiation embrittlement:
  - set-up of a mechanism framework
  - synergism of Cu, P, Ni, Mn on radiation stability by model alloys results analysis
  - role of Mn and Ni on embrittlement of high Ni steels by VVER-1000 surveillance data analysis (RRC-KI co-operation)
  - study of the effect of the dose rate and stress (co-operation UNRI Ukraine)
  - feasibility of micro-structural analysis in materials damage evaluation
- Development of HFR irradiation rigs and irradiation campaigns: irradiations for FRAME and PISA projects
- Development of non-destructive methods to monitor ageing (based on electric, thermo-electric, magnetic)
- Creation of a new activity /network/sector on reactor internals (AMALIA)
- Impact testing capabilities development
  - preliminary fracture toughness testing by dynamic impact using pre-cracked CVN specimens
  - validation of test practice of miniaturised (KLST) specimens



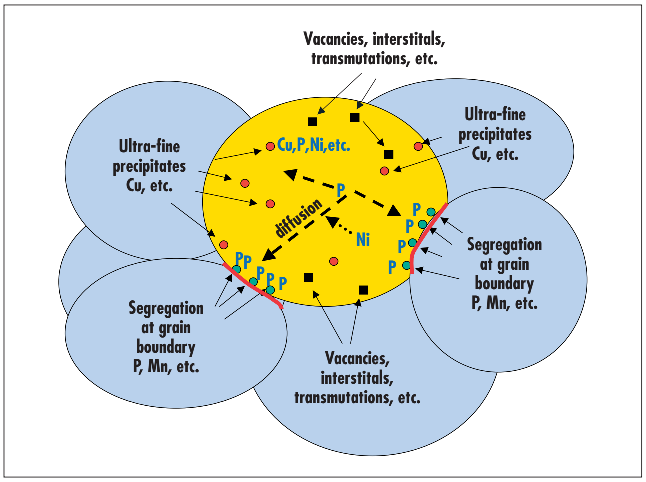
WWER-440 RPV forgings data

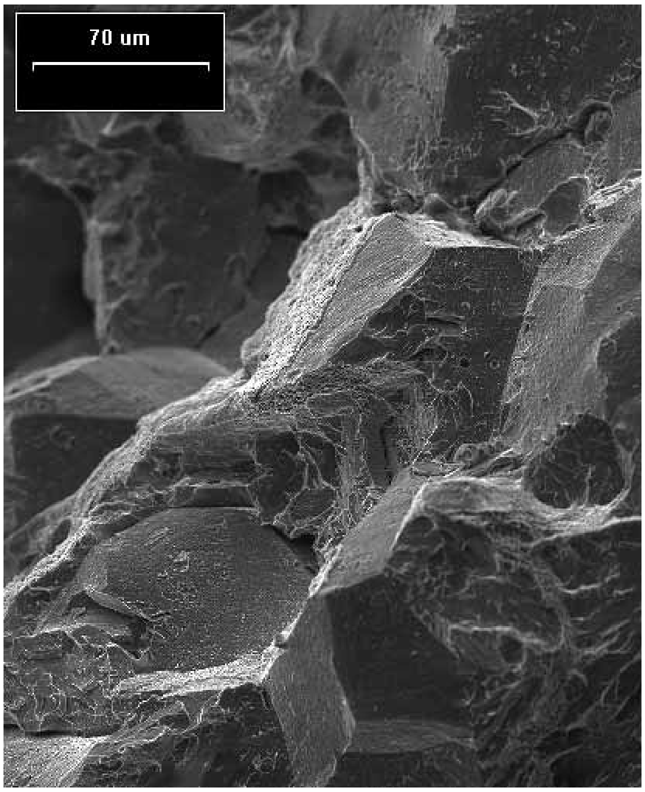


DBTT correlation between CV and KLST



Irradiation embrittlement



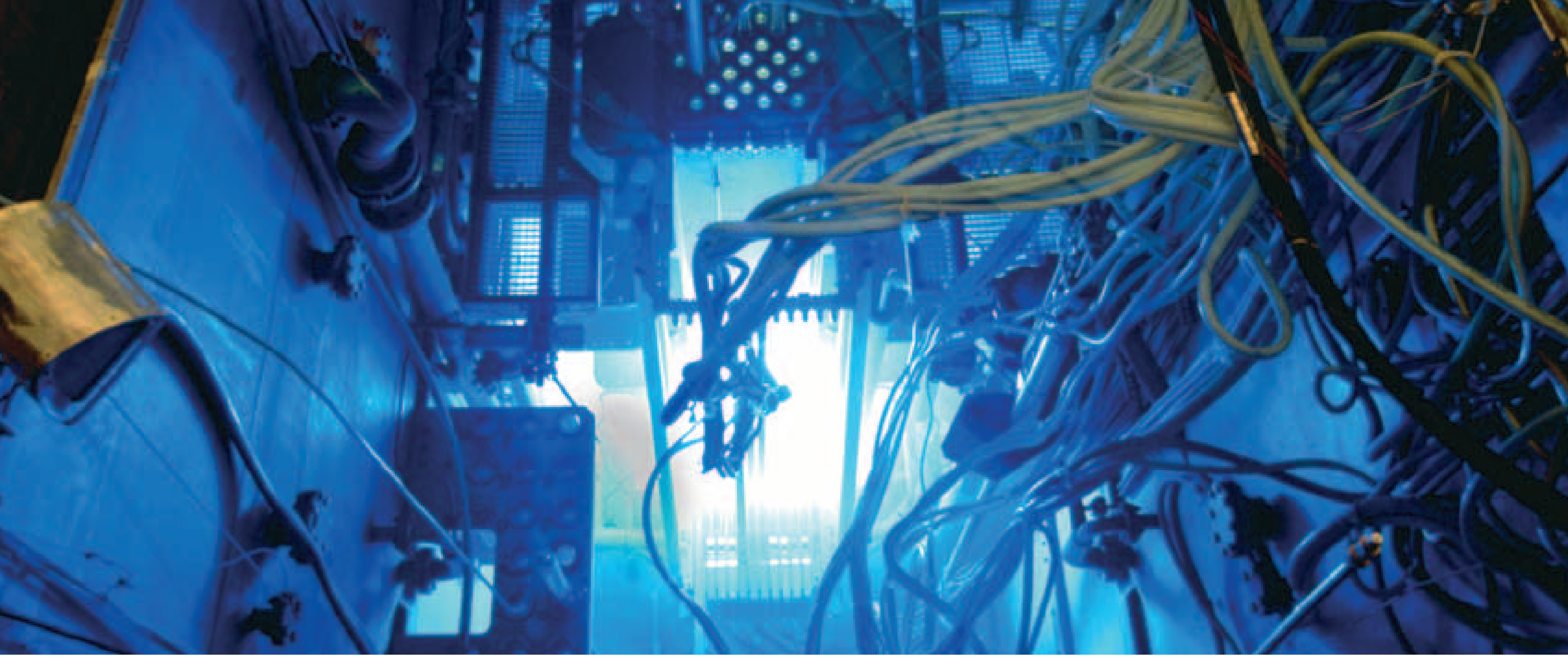


European network management & support to European network strategy

The JRC has continued to support the European Network (E.N.) AMES (Ageing Materials European Strategy) in 2002. AMES E.N. started its activity in 1993 with the aim of studying ageing mechanisms and remedial procedures for structural materials used for nuclear reactor components.

Operated by JRC-IE, AMES E.N. tackles plant life management issues by supporting the development of partnership projects and carrying out research projects. Examples of issues tackled (with relevant projects undertaken) are:

- development of non-destructive techniques applied to thermal ageing and neutron embrittlement monitoring (GRETE, following AMES-NDT)
- improved surveillance for VVER 440 reactors (COBRA)
- dosimetry (REDOS following AMES-DOSIMETRY & MADAM)
- chemical composition effects on neutron embrittlement (PISA) and
- advanced fracture mechanics for integrity assessment (FRAME)
- consolidation of the understanding of PLIM issues and of radiation embrittlement in particular (ATHENA)



HTR-TN (High Temperature Reactor Technology Network)

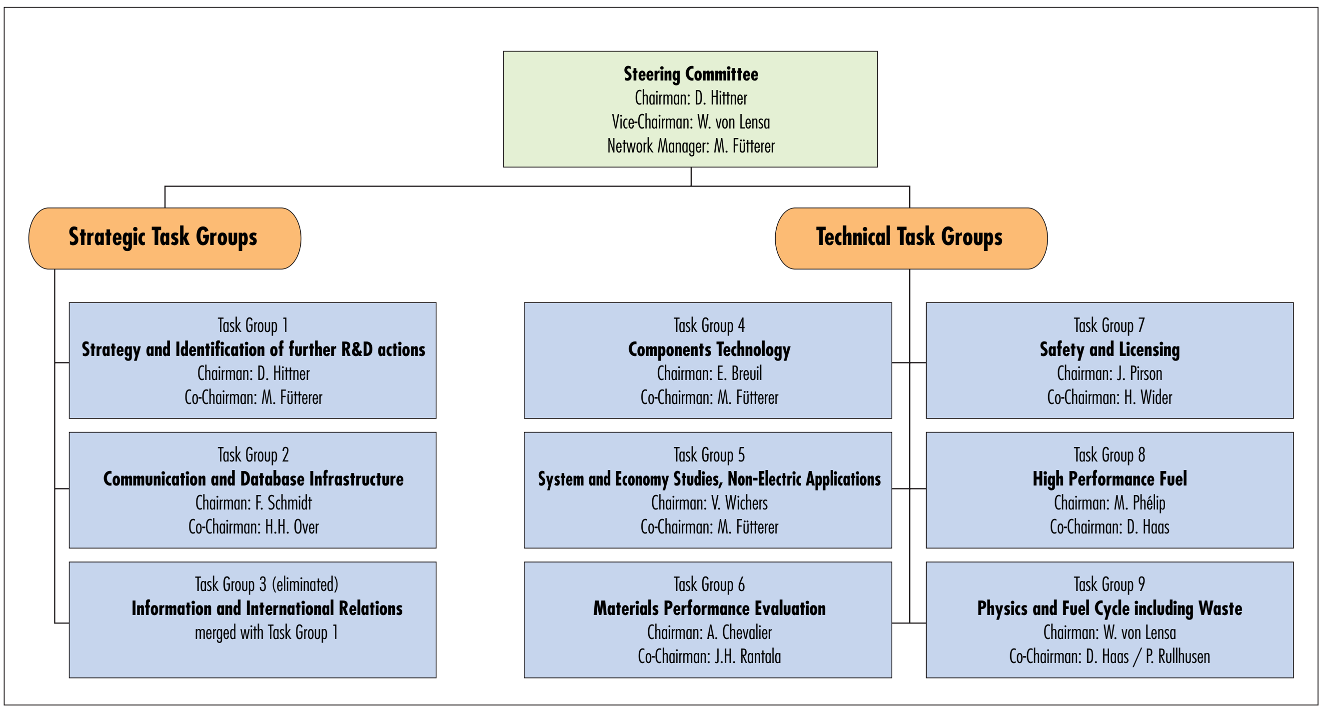
Objectives

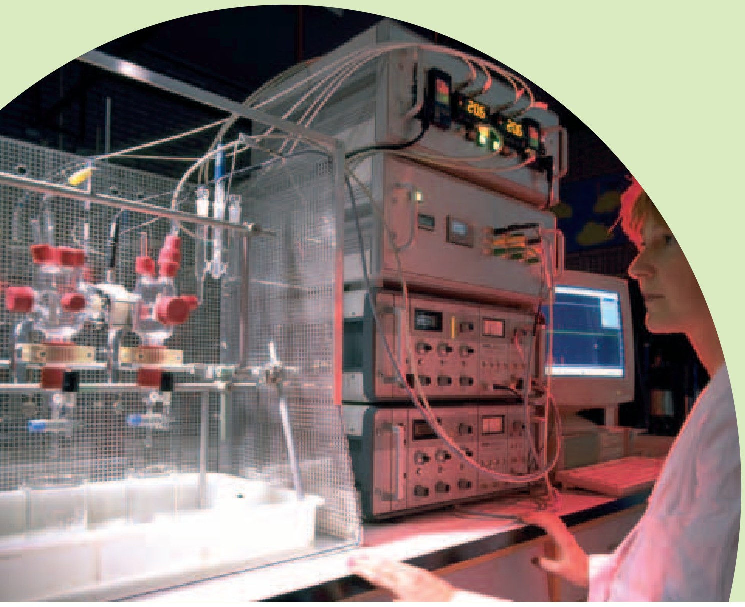
In response to growing interest in HTRs world-wide and on the initiative of JRC, HTR-TN was established in April 2000 to recover, maintain and develop HTR technology from Europe and elsewhere. The ultimate goal is the development of advanced HTR technologies thus supporting industry in the design of power plants, which comply with stringent requirements in terms of sustainability, economic competitiveness, safety, waste and social acceptability. Since its creation, HTR-TN performed very successfully and contributed to an efficient EU-wide exchange including the organization of specialist meetings, seminars and conferences. It co-ordinated HTR related R&D projects within the EU's 5th Framework Programme and is preparing a new, consistent Integrated Project for the 6th Framework Programme starting in 2003. Further information can be found at www.jrc.nl/htr-tn.

Achievements in 2002

JRC-IE continued operating this network, which is currently driven by 21 partners and observers from research and industry and is still growing with new partners from candidate countries. JRC also co-chairs all HTR-TN task groups (see organization chart below) dealing with the detailed technical achievements and with the co-ordination of R&D work among the partners. JRC-IE has further taken several initiatives to trigger closer co-operation with organizations in non-European countries. A particular highlight was the organization of HTR 2002 in Petten, a conference that attracted almost 200 international specialists from all technical areas. The proceedings are available at www.jrc.nl/htr-tn (Events). A follow-up meeting is foreseen in Petten in April 2004 and is expected to become a regular event.

Figure 5 **HTR-TN organization chart**





The NET European Network on Neutron Techniques Standardization for Structural Integrity

Objectives

The aim of NET is to support progress towards improved performance and safety of European energy production systems.

The state of the art in assessing internal stresses, micro-structure and defects in welded nuclear components - as well as their evolution due to operational loads and irradiation exposure - needs to be improved before relevant structural integrity assessment code requirements can safely become less conservative. This is valid for both experimental characterisation techniques and predictive numerical algorithms.

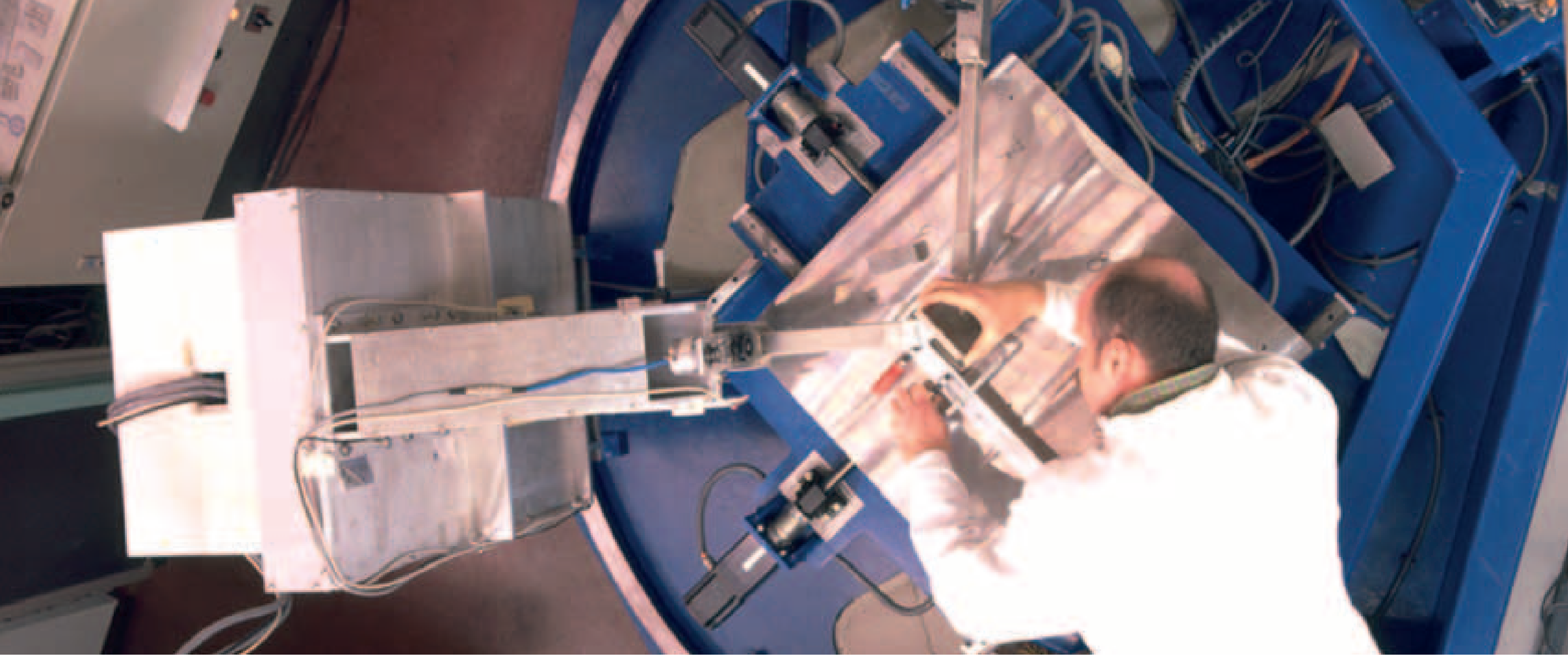
To address this need, 35 major industrial and research/academic organisations have joined forces, under JRC co-ordination, to launch NET in May 2002, representing major nuclear industries and most European neutron facilities from 7 EU states and 5 Candidate Countries. During 2002 the NET consortium has developed three initial Technical Task Groups (TG).

TG1
Basic research pilot study on residual stress analysis of a single bead weld on a steel plate (to be conducted with more than 15 partners).

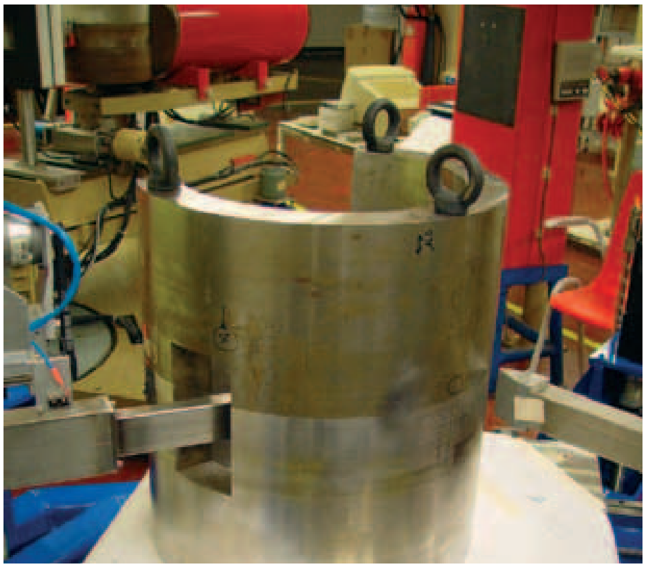
TG2
Parametric study aiming at the valuation of stress relief heat treatment in welded Cr-Mo-V steel plates (to be conducted with more than 10 partners). This study is viewed as a starting activity toward the development of novel heat treatment methods relevant to repair welding.

TG3
Investigation of thermal ageing effects (micro-structure and defects analyses) on cast duplex stainless steels based on small angle neutron scattering (SANS).

Figure 6 **NET kick-off meeting**



NET related HFR facilities



The HFR neutron beam facilities have enabled JRC to play a leading role in the development and standardisation of neutron methods at European and International level. Two neutron diffractometers - HB4 and HB5 – have been used for microstructure, texture and stress investigations in structural components. HB3b and HB8 are used for defect analyses based on small angle neutron scattering and radiography respectively. In the course of 2002 progress has been made toward enhancing the performance of HB4 and HB5 and re-commissioning of HB3b and HB8. Based on these facilities a large number of experimental campaigns have been successfully completed primarily for residual stress mapping in steel alloy welds in support of institutional (NET) and competitive (ADIMEW, ENPOWER, HITHEX and INTERWELD) nuclear safety related activities. (See below).

HB4
- Call for tender launched for the development of specimen handling container (small hot cell) with dedicated specimen positioning table for diffraction testing of irradiated weld specimens;
- Call for tender launched for the development of specimen furnace and auxiliary equipment for neutron diffraction testing at high temperatures; Target date for testing of furnace: June 2003
- Hot Cell (incl. aux. equip.) operational (Target date: End 2003)

HB5
- Successful testing of performance of position sensitive detector
- Expected degree of performance enhancement: one order of magnitude
- Adjustment of detector settings completed, neutron optics alignment started
- Start of first stress measurements (Target date: early 2003)

HB8
- Partially dismantled for servicing and repair of aged parts
- Servicing of helium coolers (filter units)
- Leaks detected during performance testing in the helium system.
- Facility operational (Target date: Mid 2003)

HB3b
- Preliminary study on facility's electronics and software upgrade completed
- Necessary soft- and hardware upgrading was initiated (late 2002 – Target date: end 2003)
- Defect detected in cooling system of filter unit (Repair target date: mid 2003)

NET related standardisation activities

An international standard for "residual stress determination based on neutron diffraction" is currently being drafted by an international group of experts, appointed by CEN & ISO and convened by the NET Manager. This group of experts started its work in 2001 and the final draft Standard will be submitted for adoption in late 2003.

In addition, a new activity fully funded by DG RTD, i.e., SIANC: Marie-Curie Fellowship Project on "Structural Integrity Assessment of Nuclear Components based on Neutron Techniques" has just been started. Finally, the RESTAND project, co-ordinated by the NET Manager, was successfully completed. The main deliverable of this project provided the basis for the current CEN & ISO standardisation activity.

NET related shared cost activities

During 2002 the IE-NET team has been engaged in four ongoing SCAs (See below)

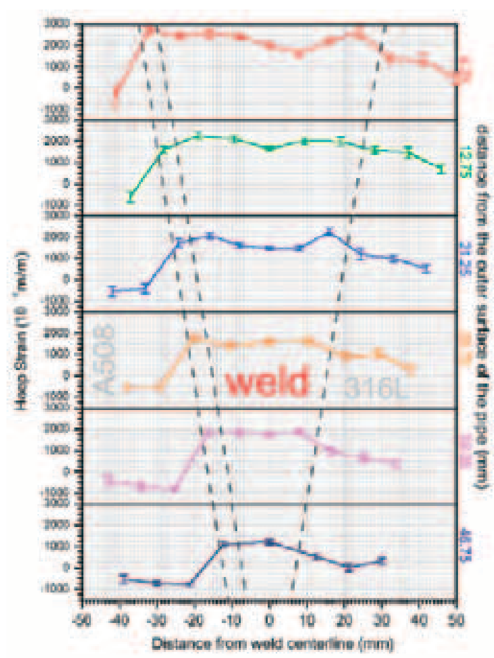
ADIMEW
- 3-D mapping of residual stresses in 51-mm-thick piping dissimilar metal weld based on neutron diffraction
- Experimental campaign successfully completed
- Interpretation of the results underway
- Data to be used for calibration of predictive FEA based numerical models.

ENPOWER
- Assessment of novel methods for weld repair
- Residual stress analysis based on neutron diffraction
- Calibration of predictive numerical models based on reliable test data

HITHEX
- Development of advanced CMCs for ultra-high temperature heat exchangers
- Residual stress investigations in C/C-SiC tubular specimens
- Testing at room and high temperatures

INTERWELD
- Investigation of stress corrosion cracking in RPV welded internals
- Measurement of residual stress evolution due to neutron irradiation

MANAGEMENT
- Structural Analysis of the HFR Vessel based on Finite Element Modelling
- Preliminary Residual Stress Finite Element Predictions of HFR Vessel Weld 22
- Global Stress Determination based on Surface Strains Relief Monitoring during Panel Removal from Vessel A West Wall
- Re-Analysis of Pressure Loads using an Updated Finite Element Model
- Elasto-Plastic Analysis of the HFR Vessel under the Design Pressure



HFR: The Programmes

HFR as a Tool for Medical Applications

Boron Neutron Capture Therapy – BNCT

Introduction

BNCT is a tumour-targeting form of radiotherapy under development, which currently can only be performed at nuclear research reactors, such as the HFR. BNCT is based on the ability of the isotope ^{10}B to capture thermal neutrons to produce two highly energetic particles, i.e. a helium (α particle) and lithium ion, which when produced selectively in tumour cells, can in principle destroy cancer cells, whilst sparing the surrounding healthy tissue, thus opening an effective new modality for cancer treatment. The first clinical trial on BNCT in Europe was started at the HFR in October 1997. Since then, other reactor centres in Europe are also performing BNCT, namely: VTT (Finland), Studsvik (Sweden) and Rez (Czech Republic), whilst programmes elsewhere continue in USA and Japan. More significantly, a novel application of BNCT was performed in 2001 in Italy (Pavia) on an extra-corporal treatment of liver cancer.

The Institutional Programme on BNCT moved forward with some significant advances in treatment planning, dosimetry and applications to other types of tumours.

The highlight of the year was the Tenth International Congress on NCT, held in Essen Germany, which was co-organised by the IE/JRC, who had the role of Secretary-General (R.Moss).

Competitive activities

Clinical trial of BNCT for glioblastoma (EORTC 11961)

The clinical trial of BNCT for glioblastoma, progressed in 2002 with the completion of the fourth cohort of 6 patients (in total since 1997: 26 patients treated in 4 cohorts). At present, no dose limiting effects have been observed and life expectancy is no worse than alternative treatment. A decision will be taken in 2003, as to whether to start a 5th cohort or not.

New clinical trials

Under the Fifth Framework Programme, three new clinical trials received approval and funding in "Quality of Life and Management of Living Resources", contract no. QLK3-CT-1999-01067. The first trial is an uptake study, which looks into the possible uptake of boron into different tumours, including thyroid cancer, head and neck cancer and liver metastases. The latter, if successful in terms of significant uptake of boron in the cancerous cells, would be the first step towards performing extra-corporal liver treatment (á la Pavia [1]) by BNCT at the HFR. The second trial has the objective to study the optimisation of the delivery of the boronated drug (BSH) in brain tumours. The purpose is to increase (double) the boron concentration in blood, thereby doubling the boron dose in the tumour, which would require only half the irradiation time to achieve similar doses to those applied in the current trial whilst only giving half the irradiation dose to the healthy tissue. The third trial will treat brain metastases of malignant melanoma using the boron compound, BPA. This last trial will be prepared in common with the EORTC BNCT Group, the EORTC Melanoma Co-operative Group and the Harvard/MIT BNCT group in the USA. The Principal Clinical Investigator is Prof.dr.med. Wolfgang Sauerwein of the University of Essen. Participating hospitals and institutes are: Universities of Münster, Reims, Essen, VU Amsterdam, Nice, Graz and München, and NRG. All three protocols are still under evaluation, but with the aim to start all 3 in 2003.

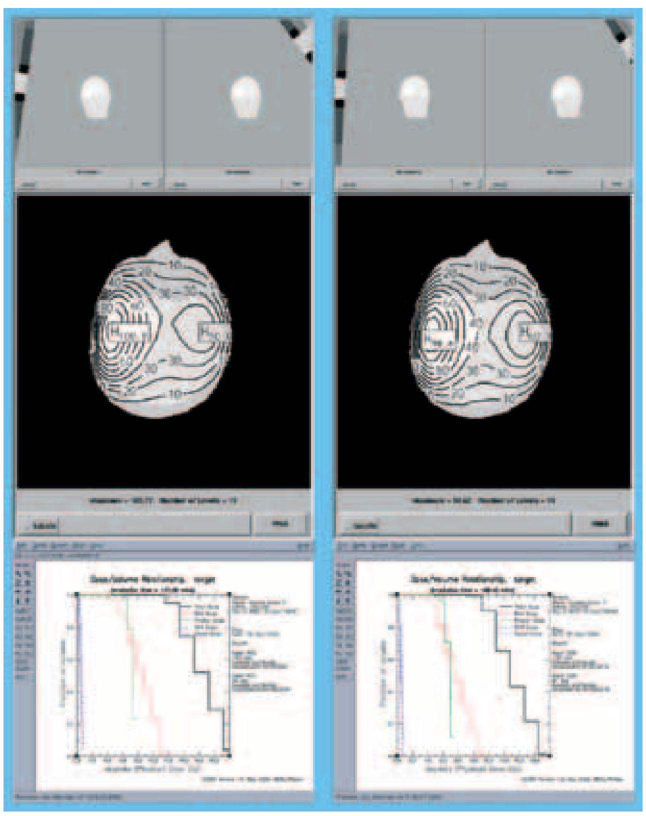
[1] T. Pinelli, A. Zonta, S. Altieri, S. Barni, A. Braghieri, P. Pedroni, P. Bruschi, P. Chiari, C. Ferrari, F. Fossati, R. Nano, S. Ngnitejeu Tata, U. Prati, G. Ricevuti, L. Roveda, C. Zonta, "TAOrMINA: From the first idea to the application to the human liver", in: *Research and Development Neutron Capture Therapy*, W. Sauerwein, R. Moss, A. Wittig, (Eds.), Bologna, Monduzzi Editore, ISBN 88-323-2909-3, 2002

Other competitive (shared cost) actions

"A Code of Practice for Dosimetry for BNCT in Europe"

The involvement of JRC in this SCA includes dosimetry measurements, MCNP calculations and writing one of the Chapters in the final Code of Practice. The first two were completed at the beginning of the year, whilst the Chapter (on Quality Control) has recently been completed. This required the approval of many of the participants as well as approval from the Medical Physicists involved in the action. The project is co-ordinated by NRG Petten.

Example of (part of) two treatment plans, displayed using the BePrO software



"Enabling Best Practice on Oncology: BEPRO"
(contract no. IST-2000-25252)

JRC Petten's role in this Shared Cost Action is part of the medical evaluation phase, where patient data and images are transferred using custom built software packages, allowing access to patient data between hospitals involved in the clinical trials at Petten. The facility allows the clinicians to review different treatment plans simultaneously on the computer screen (see figure left), allowing immediate judgements to be made as to whether a new plan is required to be made or whether one can be chosen as the preferred plan. The project is now in the implementation phase and was successfully used on 3 patients treated in this year's phase of the trial. The project is co-ordinated by the University Joseph Fourier Grenoble.

JRC institutional programme on BNCT

The research and development activities of BNCT at Petten are supported in the JRC's Institutional Research programme. The four-year programme has 4 prime objectives:

- Development and maintenance of existing facility
- Support to present trials and new trials
- Treatment planning activities
- Research activities, including: neutron beam improvement and design; application to different types of tumours; application to non-cancerous diseases; development of patient positioning devices; improvement of dosimetry; investigation of boron detection techniques; and development of microdosimetry

Continued improvements to the overall features of the facility, as well as the annual maintenance of some of the critical components in the liquid argon system were performed. A new PC was purchased to install the treatment planning code, NCTPlan, which is an American written code, used by the Harvard Medical School/MIT BNCT Group. This code will be used as part of the third clinical trial (see earlier) to start in 2003, which will be performed in parallel to the EORTC (Petten) trial.

Under dosimetry development, quite a number of measurements were performed using the water phantom. Various parameters studies were completed, which could be compared to calculations as part of an action to validate the new NCTPlan code. Measurements were also performed using new dosimetry techniques based on superheated drop detectors [2], developed at Yale University (USA).

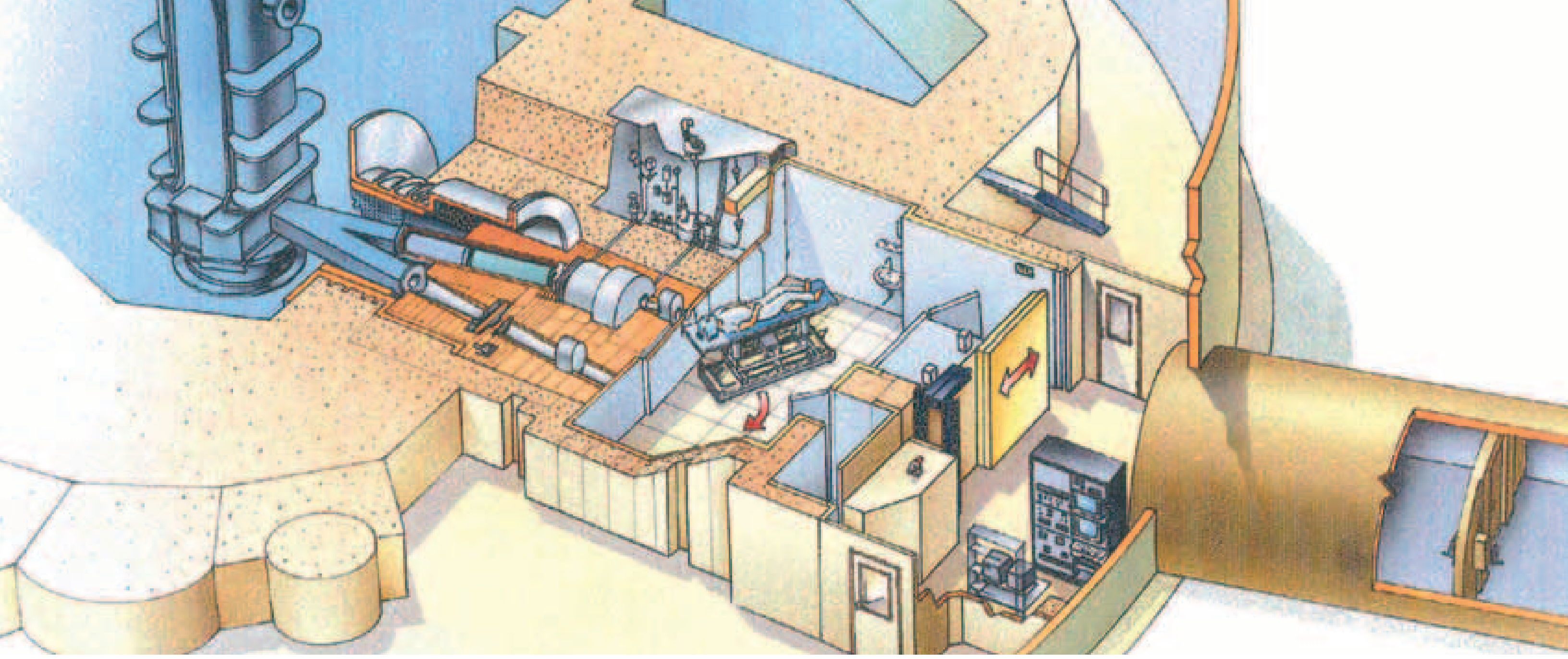
More calculations were performed to look at treating melanoma metastases in the brain, which would require a homogeneous dose distribution throughout the whole brain, and also on liver extra-corporal treatment, as carried out in 2001 in Pavia. In this respect, initial discussions were held with the University Hospital in Essen to implement such a treatment between Essen and Petten. The decision whether to proceed or not is dependent on the uptake study, mentioned above, on boron uptake in liver.

Tenth International Congress on Neutron Capture Therapy, Essen

With the University of Essen, JRC Petten was co-organiser of the Tenth International Congress on Neutron Capture Therapy, which took place between September 8 and 13 in Essen. The congress, which is held every 2 years, was a great success and attracted almost 300 participants from all around the world. There was a much greater emphasis placed on the clinical aspects of BNCT, as it is now being performed in 5 places in Europe, i.e. three more places than at the time of the last international Congress two years ago (Osaka, October 2000). Proceedings [3] were produced before the Congress and were distributed at the meeting. The JRC Petten BNCT group presented or co-authored eleven papers at the congress.

[2] F. d'Errico, V.Giusti, E.Nava, M.Reginatto, G.Curzio and J.Capala, "Fast Neutron Spectrometry of BNCT Beams", in: *Research and Development Neutron Capture Therapy*, W. Sauerwein, R. Moss, A. Wittig, (Eds.), Bologna, Monduzzi Editore, ISBN 88-323-2909-3, 2002

[3] "Research and Development in Neutron Capture Therapy", Proceedings of the Tenth International Congress on Neutron Capture Therapy, editors: W.Sauerwein, R.Moss, A.Wittig, Bologna, Monduzzi Editore ISBN 88-323-2909-3, 2002



Medical radioisotope production

Most people are not aware of the important role of nuclear medicine in modern healthcare: medical isotopes can save lives when used for early diagnosis and therapeutic treatment of diseases and are indispensable for pain relief.

One aspect of crucial importance is the regular availability of radioactive isotopes for medical applications. Under the guidance of the Association of Imaging Producers and Equipment Suppliers (AIPES) the five main medical producing European Research Reactors (see below) have therefore co-ordinated their reactor operation schedules. This allowed the medical supply chain not to be too disrupted as SCK/CEN's BR-2 reactor in Mol brought forward and extended a planned operating cycle to fill the gap left by the unscheduled HFR shutdown.

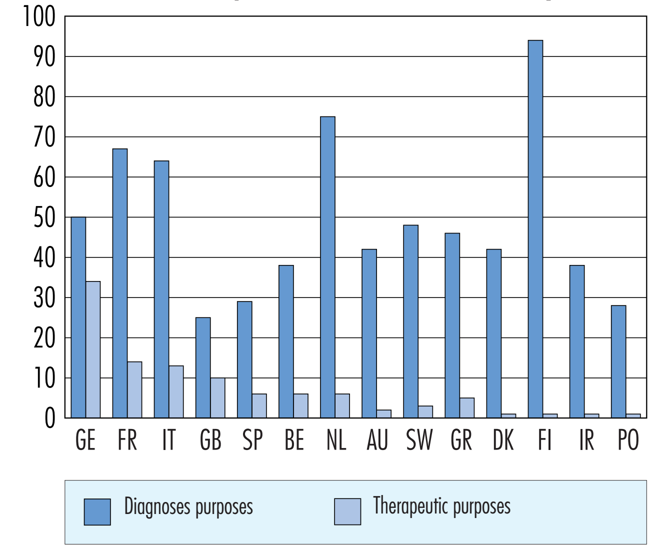
European facilities for RI production

BELGIUM	BR-2
FRANCE	Osiris
GERMANY	FRJ-2
SWEDEN	R-2
NETHERLANDS	HFR

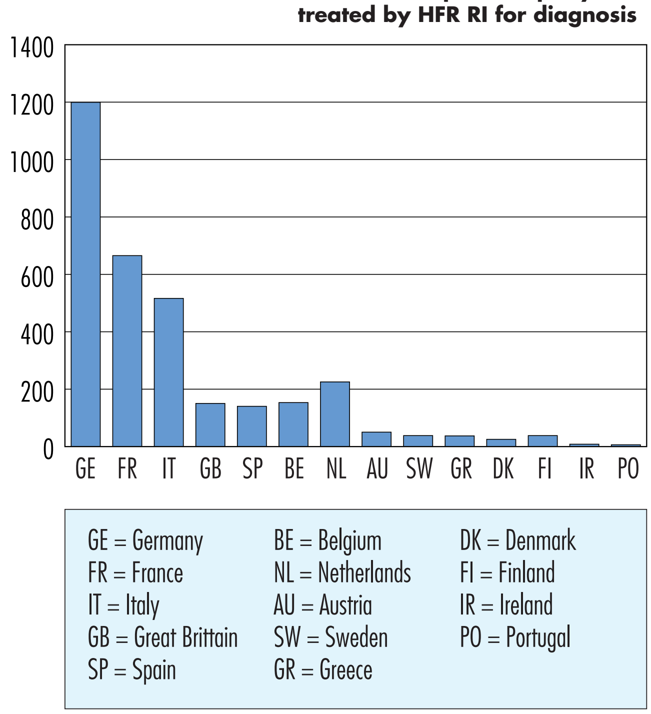
For the HFR, the year 2002 saw a considerable increase in the number of irradiations and in the production of radioactive isotopes for medical and industrial purposes. Despite the cancellation of one operating cycle in February, the irradiation quantities in terms of produced activity increased significantly and the total number of individual irradiations rose by 40%. This significant increase in irradiations was due to rising demand for key isotopes, especially the short half-life isotopes that are essential for diagnostic and therapeutic applications in nuclear medicine and radiotherapy.

The HFR share in the world production of the main reactor-produced radioactive isotopes such as molybdenum-99, iodine-131, strontium-89 and iridium-192 range between 30 and 60%.

HFR production (% of total country needs)



Thousands of patients per year treated by HFR RI for diagnosis



Over the years the HFR has also proven to be a reliable partner for medical research and development with the regular supply of lutetium-177, holmium-166 and yttrium-90. These radioactive isotopes are destined for research institutes and hospitals where they are used to label monoclonal antibodies, peptides and other small molecules. These combinations of radioactive isotope and targeting moiety emit radiation that destroys diseased tissue, while collateral damage to healthy tissue is limited.

Research on therapeutic applications has intensified in recent years and many clinical trials are underway. With the partnership of NRG, the HFR has demonstrated that lutetium-177 of appropriate quality can be supplied to medical researchers on a regular basis.

The production of iodine-125 'seeds' – small sealed sources for the treatment of prostate cancer – strongly increased in 2002. Sufficient quantities to allow the treatment of more than 5,000 patients were produced. The advantage for patients of this seed implantation therapy is that potentially debilitating local surgery can be avoided.

The production of radioactive isotopes is carried out according to HFR's high standards for safety and protection of the environment. Also an effective treatment of the (medical) waste and safe storage is arranged in contracts with the Dutch Central Organisation for Nuclear Waste (COVRA). This ensures that the back-end of this production process is secure and well managed. In an additional activity (carried out by NRG), the components of thousands of technetium generators are cleaned at NRG and prepared for re-use in hospitals all over the world.

In 2003, a continued increase in the range and volume of isotopes production is expected. Further, HFR's privileged partner, NRG, is carrying out an increasing number of research projects with a range of different partners.

EMIR

Nuclear medicine and radiotherapy make a vital contribution to the diagnosis and treatment of major disease. This role is likely to expand with new developments including availability of new medical isotopes. Building on HFR's position in the medical radioisotope production field, EMIR (**E**uropean Network for **M**edical radio**I**sotopes and Beam **R**esearch) was initiated in 2001 by the JRC-IE to identify and solve difficulties that constrain nuclear medicine and radiotherapy development in Europe and facilitate closer interdisciplinary collaboration. Participating organisations include the main European associations of medical radiation specialists, radiopharmaceutical radioisotope producers, nuclear research reactor institutions, research organisations and the JRC. The steering committee established task groups focusing on eight key areas for development. Liaison with non-European organisations will be encouraged. In 2002, the EMIR project continued to increase the number of partners in the network, e.g. the Rez Institute from the Czech Republic.

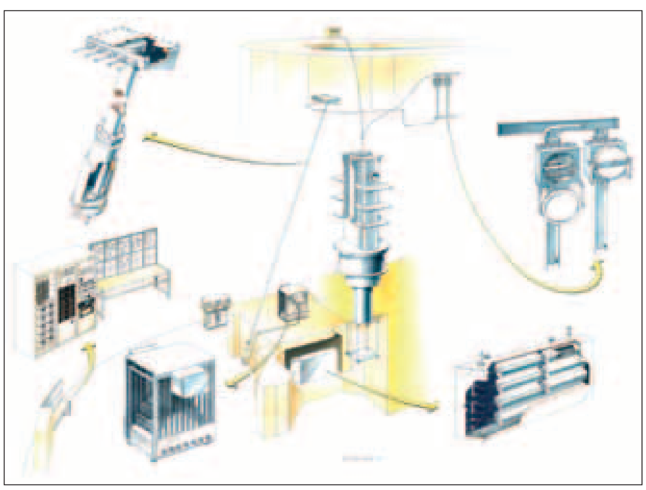
Due to the departure of the Project Leader in early 2002, the project could only function on a low level. Nevertheless, it was possible to proceed on two of the many actions within the EMIR Network. In the task group "Radioisotope Availability", it was agreed (overwhelmingly) that a Survey on Radioisotopes was needed to complement existing surveys on available facilities, PET and an ESTRO survey on certain radioisotopes. The present survey should concentrate on isotopes for therapy, research, availability capacity and identify areas in Europe where shortages occur. Furthermore, JRC agreed under the auspices of EMIR to co-organise the Fifth International Conference on Isotopes to be held in Brussels in 2005. At the Fourth International Conference, held in South Africa in March, Philippe Jehenson from the EMIR Group presented a paper, entitled "A European Network for Nuclear Medicine and Radiotherapy: EMIR".

HFR: The Programmes

HFR as a Tool for Fission Reactor Technology

Currently operating Light Water Reactors (LWR) and Gas Cooled Reactors (GCR) were designed decades ago and were limited in temperature and performance due to the restricted availability of qualified materials and the choice of coolants. Besides many undisputed advantages, they also have several drawbacks such as: large unit size, high investment costs, long write-off times, relative complexity, limited efficiency etc. High Temperature Reactors as near-term (2010) options feature numerous advantages as replacements of third-generation LWRs or GCRs and as new installations. Several HTR evolutions have been evaluated in the international Generation IV initiative. Feasibility studies for several advanced conceptual designs are conducted in a number of research institutes and universities worldwide to optimize aspects such as safety performance, sustainable use of fuel, minimization of waste, or economy. In Europe, significant efforts are dedicated to the recovery of the knowledge on the once fully mastered fuel fabrication and on the qualification of materials.

Euratom is interested in participating in and supports Generation IV and can provide significant input from past HTR experience and for emerging projects on gas-cooled reactors. The JRC-IE contribution is integrated in projects providing technical contributions in the fields of fuel and material irradiations, out-of-pile testing and data management. The strong on-site synergies between NRG and JRC installations are used and the long-term expertise in advanced materials development and irradiation testing in the HFR is maintained and constantly improved.



HTR fuel irradiation rig and telated auxiliary equipment in the HFR

HTR fuel irradiations

Objectives

The irradiation of LEU fuel types in the HFR is under preparation to study in particular its resistance to radioactive fission product release with increasing burn-up. Pre- and post-irradiation examinations will be conducted to test the safety relevant quality and temperature limits of the irradiated fuel. The results of these experiments are expected to provide orientations for further improvement of fuel technology. More specifically, the irradiation projects are:

- Irradiation of pebble type fuel produced by NUKEM, Germany and INET, China, codename HFR-EU1 with on-line fission gas release monitoring.
- Irradiation of pebble type fuel produced by NUKEM, Germany to high burn-up, codename HFR-EU1bis with simplified fission gas monitoring.
- Irradiation of compact type fuel produced by General Atomics, USA, codename HFR-EU2 with on-line fission gas release monitoring.

Achievements in 2002

For all three irradiation tests, detailed design studies were performed including drawings and instrumentation. Neutronic and thermal analyses were subcontracted. The irradiation HFR-EU1bis was set-up additionally to catch up with the delay of the two other irradiation tests by providing irradiated fuel spheres for safety-relevant thermal ramp tests at JRC-ITU. For HFR-EU2, JRC-IE successfully managed to use pre-irradiated fuel compacts with confirmed excellent fission product retention properties (delivered by General Atomics). For all irradiation tests, fabrication and subcontracting was launched. The gas circuits with fission gas analysis systems were designed and assembly has started.

In the future, further irradiation tests of advanced MOX, plutonium or thorium fuel as well as specific fuel for the incineration of nuclear waste in HTRs may be envisaged.

HTR: structural materials irradiation and out-of pile tests

Objectives

These tests aim at investigating the in-pile and out-of-pile properties of high-temperature materials to be used within an HTR core, e.g. as pressure vessel material and for control rods. Specimens of candidate materials will be irradiated at temperatures typical for their envisaged use in an HTR. Post-irradiation testing will focus on determining the mechanical properties. The materials to be tested include metallic super-alloys or ceramic and fibre composite materials. The exposure in particular of the metals for longer periods to high temperatures and different helium chemistries may carburize or decarburize them, thus altering their mechanical properties; this alteration has to be quantified.

Achievements in 2002

Significant out-of-pile material testing activities were prepared for the conventional part of an HTR power plant, in particular for high temperature helium turbines and helium-helium heat exchangers. The required installations were designed, modified and tested.
For the future, irradiations of improved graphite and reflector materials as well as alternative matrix materials and neutron poisons may be envisaged.

Development of an HTR fuel database

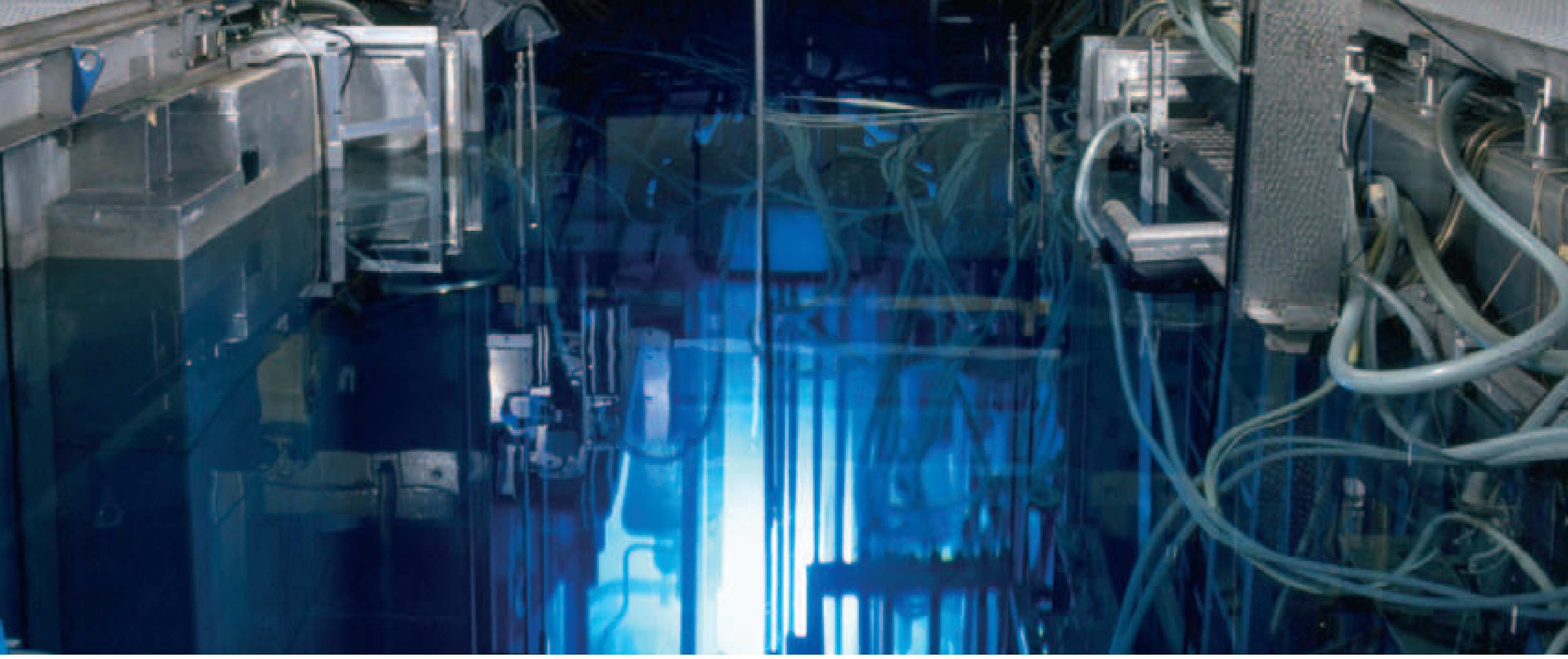
Objectives

Numerous irradiation tests of earlier HTR fuel types were already conducted some 30 years ago in the HFR and elsewhere. In this context, a database application (Fuel-DB) for experimental results was developed in order to recover, maintain and utilize a maximum of HTR fuel related information. The success of the Fuel-DB activity is obviously dependent upon the quality of the data input. Whilst the immediate objective is to recover a maximum of data from archived documents, the primary aim is to ensure that in the future, experimental data is stored at the source, i.e. piped directly from the test facility to the database.

Achievements in 2002

In co-operation with the HTR-F project, the structure, i.e. the type and degree of detail to be listed, of the fuel database was defined. The database is operational and ready to be filled with data by the project partners.

Future work on the HTR fuel database will concern essentially the maintenance and minor upgrades as required by the project.



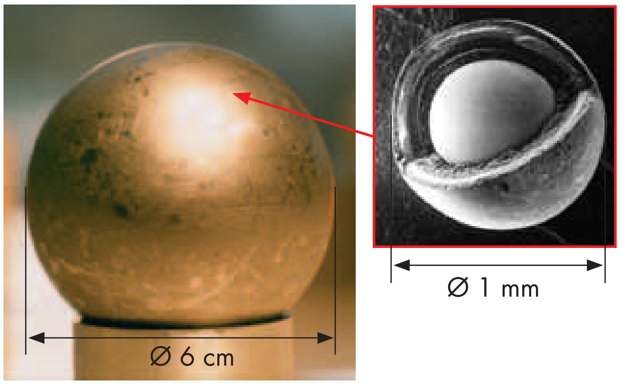
The transmutation of americium

Within the European framework EFTTRA the transmutation of americium and the fission products iodine and technetium are studied. Two fuel capsules containing either sub-micron particles of americium oxide (T4-bis) or uranium oxide (T4-ter) in a $MgAl_2O_4$ matrix have been prepared by ITU (T4-bis) and NRG (T4-ter) and were irradiated in the HFR. The irradiation lasted 653 full power days and was completed successfully in December 1999.

The americium burn-up in the T4-bis sample is 99.8% and the overall actinide burn-up is 57%. The central temperature of the T4-ter pellets was measured continuously during the irradiation. It is observed that the temperature decreases gradually indicating that the thermal conductivity of $MgAl_2O_4$ shows suitable behaviour during irradiation.

The Post Irradiation Examination (PIE), which was performed in the hot cell laboratory of NRG-Petten, was completed in 2002. Non-destructive PIE was done on both capsules, while on the T4-ter capsule also destructive PIE has been done. The irradiation revealed strong swelling of the $MgAl_2O_4$ based fuel. Therefore, other types of inert matrices such as zirconia and new design are currently being investigated.

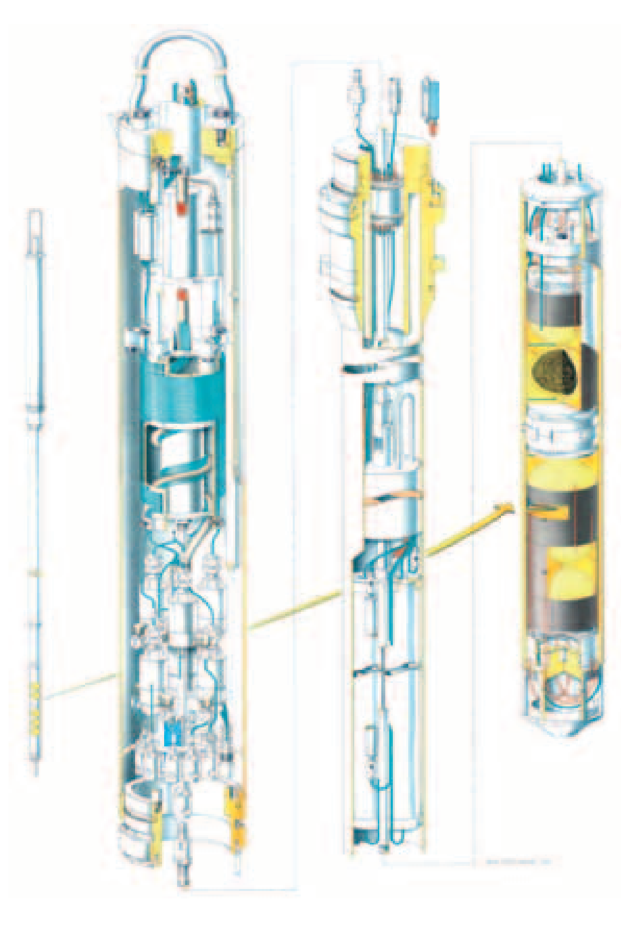
The main conclusion from the above research is that the transmutation of americium to a high burn-up has been shown successfully.



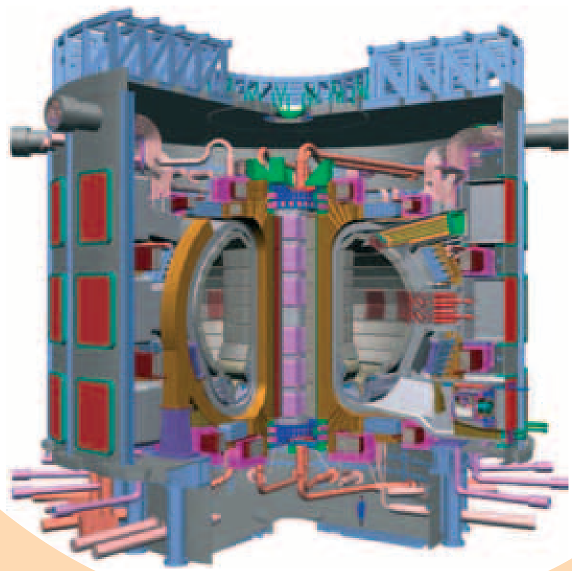
TRISO coated fuel particle and fuel pebble

TRABANT- 02

The experiment, sponsored by FZK and ITU Karlsruhe, aims at assessing the irradiation behaviour of two mixed oxide fuel pins with a high Pu content (40-45%) up to medium burn-up. The first phase of 2 cycles was completed at the start of the year. The resulting neutron radiograph indicated no damage and excellent condition for the fuel pellet/cladding integrity before the second irradiation phase. This second phase will start in 2003, after the third fuel pin, currently under manufacturing at ITU, is delivered (expected date early 2003). The irradiation will then continue for another 9 reactor cycles.



HTR fuel pebble irradiation test HFR-EU1



HFR: The Programmes

HFR as a Tool for Fusion Reactor Technology

Introduction

Efforts for development of electricity generation from fusion started in the middle of the last century and aim at achieving industrial production of energy from fusion power plants in the middle of the 21st century. At the end of the 20th century the Joint European Torus (JET) experiment could produce tens of Megawatts during a short period of time. That amount of energy produced is tens of magnitude superior to results achieved through plasma experiments in the fifties. The next step for production of energy from fusion is the International Thermonuclear Experimental Reactor (ITER), which is designed to produce 500 thermal Megawatts during pulses lasting at least 1000 seconds and expected to operate in the next decade, using deuterium and tritium as fuel.

To carry out the European effort on fusion technology development, national research centres have joined forces in the European Fusion Development Agreement (EFDA), which, along with Japanese and American partners supports ITER; Chinese and South Korean partners are expected to join the initiative in the near future. The important involvement of the EU (Spain and France are candidate for hosting the reactor) in the ITER initiative is also reflected in the HFR programme, as it remains a highly versatile device with extremely relevant R&D capabilities for fusion power plant technology. The HFR contributes to the fusion technology development by providing experimental results utilising the HFR as the neutron source and the hot cell laboratory to perform post-irradiation testing. The main areas of interest are the ITER vacuum vessel, the blanket development, and the development of the reduced activation materials: chromium steel and ceramic composites.

The irradiation of the blanket sections with lithium ceramic pebbles is not limited to post-irradiation testing, but it includes the complete in-pile instrumentation for the operation of the helium extraction circuits of the module. In this way the HFR provides valuable in-pile process data for blanket operations in ITER.

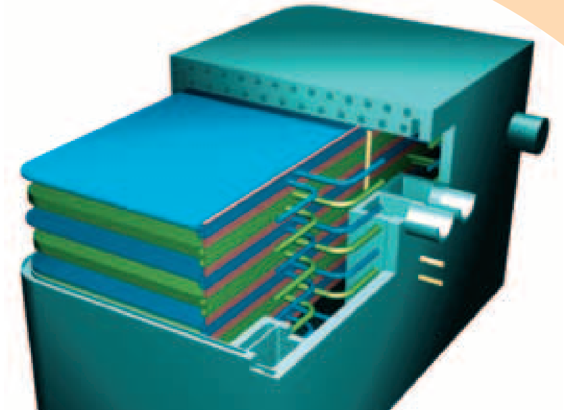
ITER vacuum vessel

Welding is the main technology for manufacturing, maintenance and repair of the ITER vacuum vessel. The vessel is made from Type 316L(N) steel. During operation, helium forms in the steel and welds due to the nuclear transmutation reaction with thermalised neutrons and boron. The vacuum vessel is located away from the plasma but where the neutrons have thermal energies near the welds. If re-welding of irradiated Type 316L(N) steel is required (e.g. for maintenance) the helium can re-arrange itself in such a way that the heat affected zone near the weld will fracture in a brittle manner. Hence, there is a need to study, assess and model the mechanical properties (particularly welding-induced brittle fracture) of 316L(N) steel in terms of helium levels. Furthermore, this must be studied for various welding procedures as these could even be adapted to decrease the brittle tendency to a certain degree.

In this framework, 10 mm thick plates have been irradiated in the HFR and welded afterwards in the hot cell laboratory to assess the maximum helium level the steel can be welded without brittle fracture.

Modelling of the welding process and the helium transport in the heat-affected zone has then been carried out to explain the observed behaviour and determine the limits for the allowable amounts of helium / boron in the steel.

Another structural solution contemplated in the present ITER design is bolting although the relaxation of the bolt force (under neutron irradiation) remains of great concern. In the HFR, an irradiation programme of stressed bolt materials such as Inconel625+ and martensitic steel PH-13-08Mo is underway. Target dose levels of 0.5, 1.0 and 2.0 displacements per atom (dpa) have been selected. The stress relaxation occurring during neutron irradiation is then measured after irradiation .



Helium cooled pebble bed blankets

In ITER, the tritium will be made from lithium in so-called blankets; the feedstock for the (tritium-breeding) lithium will be in the form of ceramics or lithium lead. In this framework, investigation of lithium ceramics continued in 2002 in the HFR's EXOTIC rig. The tritium laboratory will be used to obtain the maximum information from this series of irradiations.

As well as the testing of lithium ceramics, relevant sections of the blanket test module for ITER will be manufactured. They will be tested in 2003 in the HFR core, which provides a suitable neutronic environment, simulating very well ITER blanket module conditions and anticipated dose levels. The nuclear calculations have been finalised for a rig containing four test elements. Tests of mock-ups have been at the basis for the heat transfer analyses; FZK provided the characteristics of pebble bed deformation for the model; X-ray inspection and image analyses provided the pebble bed compaction levels needed for all the analyses. Preparations for setting-up the testing environment is well underway: the 72 thermocouples, 8 purge lines and 4 self-powered neutron detectors were in place in December; the HFR tritium measuring station has been slightly revised and updated and the visually oriented behaviour monitoring equipment for the four test elements has been completed.

Other preparations for HFR irradiations concerned the high fluence irradiation of lithium ceramics and beryllium pebbles. Out of pile tests lead the way to the final configuration of pebbles and contact with the containers. Also creep testing determines the final design for the high dose lithium ceramics irradiation named HICU.

The HIgh DOse BEryllium irradiation rig (HIDOBE) will provide experimental data for the required beryllium grades, tritium transport and thermo-mechanics of beryllium pebble beds in ITER. The microstructure of the material will be another variable. Helium production inside beryllium will be of major concern. The HFR neutron spectrum allows a highly relevant peak production level of 1500 ppm helium per annum, which is highly relevant for fusion blanket applications.

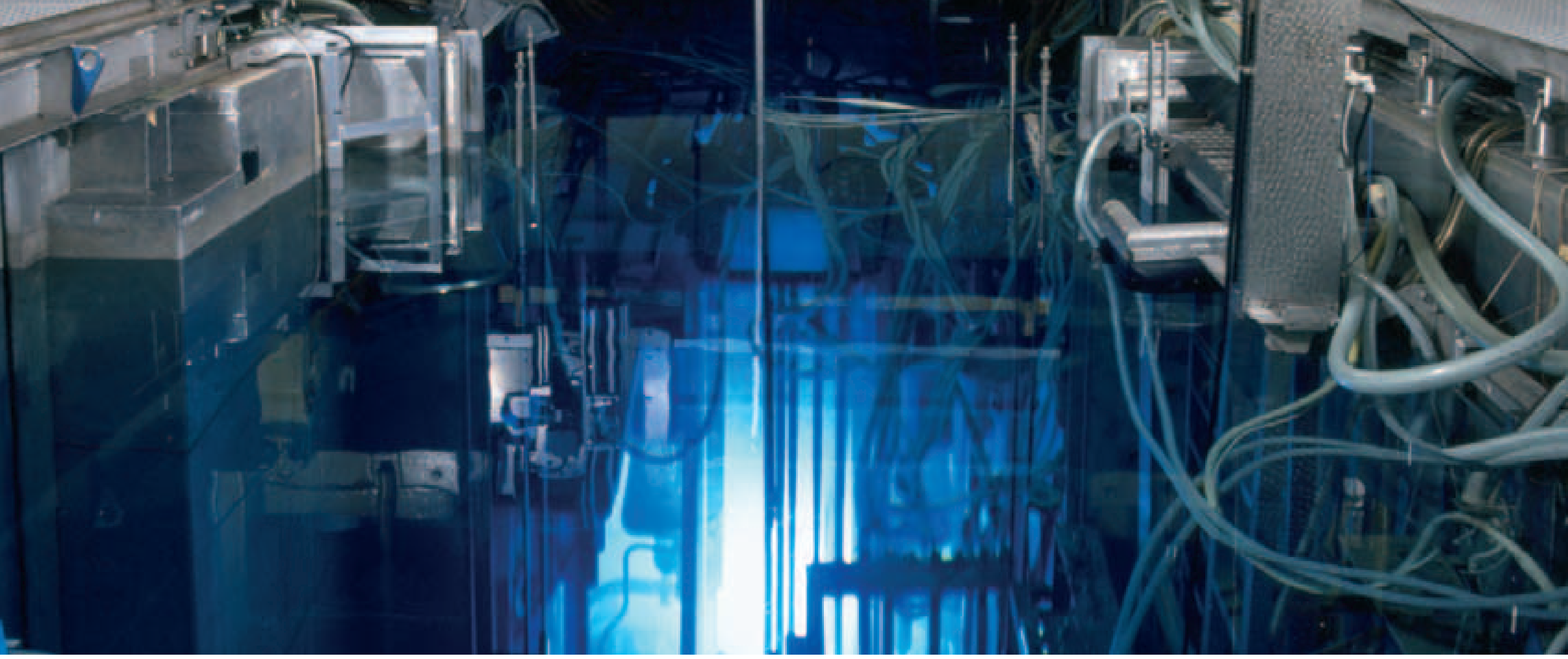
Steels for the ITER test blanket module

The reference steel for the ITER test blanket modules is EUROFER97, whose composition potentially provides a relatively short re-cycling period (less than a hundred years). The European industry has demonstrated the capability of producing such steels with low levels of impurities with already-existing standard equipment. Hence, if the need arises, reducing activation levels could be achieved at reasonable cost through the development of dedicated low impurity steels fabrication equipment.

Given the rather complicated shapes of blanket modules, their fabrication requires different product forms. In addition, as the mechanical and thermal loads of the blankets are complex, mechanical testing of the steels to determine the design limits in irradiated conditions therefore are mandatory.

In 2002, steel plate and hot iso-statically pressed (HIP) powder parts have been subjected to post-irradiation creep. The HFR neutron irradiation preceding the testing was carried out at temperatures of nominally 800 K to damage levels of 2.5 and 5 dpa. It turns out that the HIP parts showed a variability, which can be attributed to their limited homogeneity.

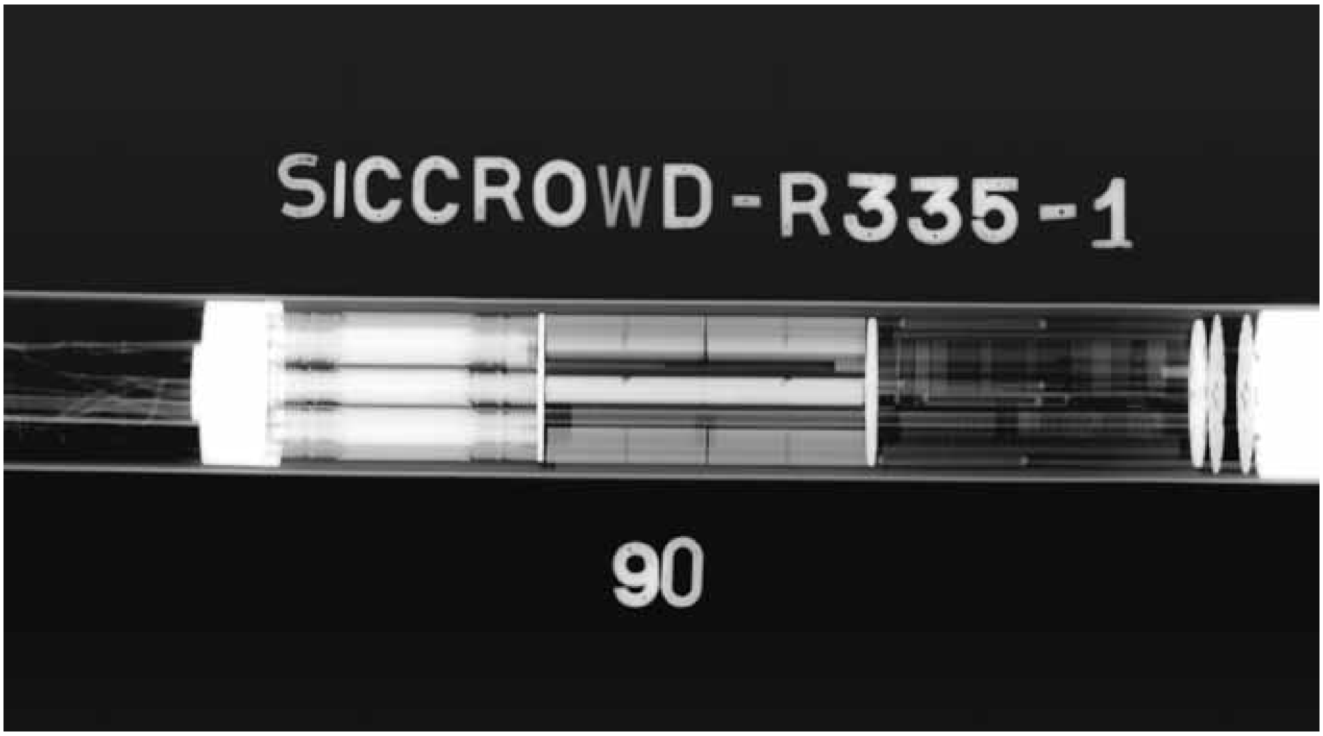
Furthermore, the HFR neutron irradiation was concluded up to a damage level of 10 dpa. Although this damage level exceeds the level anticipated and required for the ITER test module, it is relevant for the development of steel for power plant breeding blankets. Given that the neutron flux of the HFR is too low to accomplish end-of-life conditions, the HFR SPICE capsule aims for a maximum level of 15 dpa at lower temperatures. While the BOR-60 fast reactor carries out a sister programme with higher dose levels (over 30 dpa) but with temperature levels exceeding 600 K. Combination of HFR base data and that from BOR-60 irradiations must provide the prospects for utilisation of the steels for high dose applications for the time being.



Ceramic structural materials

Fusion power plants, expected to be operational around mid 21st century, will have to meet certain environmental impact as well as cost efficiency standards. The pre-requisite to meeting these targets is high thermal efficiency which starts with the utilisation of high temperature resistant structural materials. Ceramics inherently have high temperature strength, but also brittle fracture properties, which can be reduced through fibre-reinforcement. In this sense, silicon carbide composite materials, which combine high temperature strength and low activation properties (shown by the limited activation of its constituents near fusion plasma), are included in the materials development part of the EFDA long-term fusion technology programme. Several problems brought about by neutron irradiation remain to be solved as the composite becomes brittle and suffers from helium transmutation products generated by the neutron flux. Several solutions varying from more suitable fibre production to special fibre ceramics interface layers must therefore be tested in a fusion power plant simulating environment.

The HFR can simulate the conditions for the near plasma locations where the application of silicon carbide is expected. The SICCROWD rig, containing hundreds of silicon carbide composite specimens made by suppliers in the EU, Japan and the US, was irradiated at nominal temperatures of 900 and 1200 K. Before and after the irradiation the elastic modulus and the heat conductivity will be determined in order to eliminate the specific differences of specimens. The SICCROWD irradiation was successfully completed in 2002 up to 5 dpa. Post irradiation examination will be conducted in 2003.



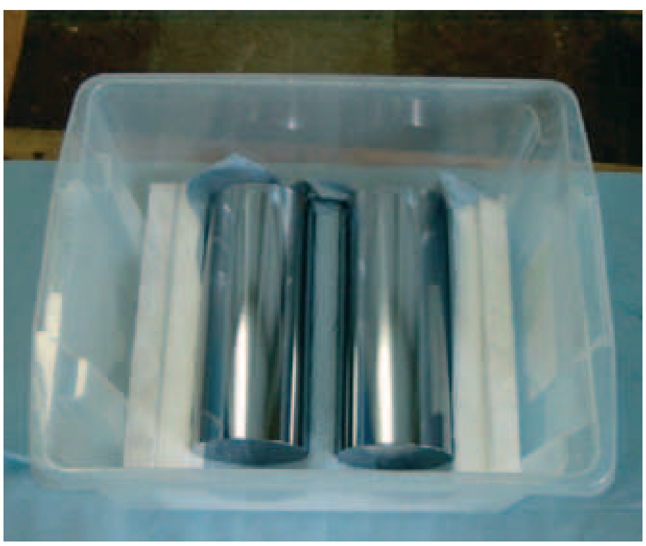
HFR: The Programmes

HFR as a Tool for Industrial Applications

The irradiation of silicon

Single crystalline silicon is used for the production of a large range of electronic devices, such IC-chips, transistors and diodes. The electrical resistivity of the silicon should be optimised for the specific application. The high electrical resistivity of high purity silicon can be decreased by adding phosphorus (n-type doping). Adding phosphorus can be done either chemically (during the production of the single crystalline silicon from a bath of molten silicon) or by neutron irradiation of the single crystalline silicon. The latter process is called neutron transmutation doping (NTD). A piece of silicon is exposed to a thermal neutron flux leading to a transformation of the silicon atoms into phosphorus atoms. The main advantage of this technique resides in the very homogeneous phosphorus distribution obtained, yielding the very homogeneous resistivity required for specific applications (e.g. rectifiers for high-voltage DC transmission).

In the HFR, such neutron irradiations on cylindrical silicon ingots (diameter 100 mm, height about 250 mm) are performed on a commercial scale. The main technical challenge for the irradiation of the silicon ingots is to obtain a homogeneous thermal neutron distribution in the complete silicon ingot. This is done by continuous rotation of the ingot and by local absorption of the excess neutrons. In order to optimise the local absorption, so-called Monte Carlo neutron distribution computations are performed, calculating the spatial distribution of the thermal neutrons inside the ingot, whilst taking other factors into account such as the complex geometry of the HFR, the neutron absorption shields and the silicon ingot. These computations are currently used to design facilities that can be used for the irradiation of silicon ingots with a diameter larger than 100 mm.



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Glossary

ADIMEW	Analysis of DIssimilar MEtal Welds
AMES	Ageing Materials Evaluation Studies
BEPRO	BEst PRactice on Oncology
BIMET	Structural Integrity of Bimetallic components
BNCT	Boron Neutron Capture Therapy
BWFC	Boiling Water Fuel-element Capsule
BWR	Boiling Water Reactor
CAPRA	Consommation Accrue de Plutonium dans les RApides
CEA	Commissariat à l'Energie Atomique
CEN	The European Committee for Standardization
CFC	Carbon Fibre Compound
CHARIOT	Charpy and Compact tension specimens Irradiation
COVRA	Centrale Organisatie Voor Radioactief Afval
DBTT	Ducktile to Brittle Thermal Transition
DPA	displacements per atom
EBP	European Blanket Project Programme
ECN	Energieonderzoek Centrum Nederland
EFTTRA	Experimental Feasibility of Targets for TRAnsmutation
EMIR	European network for Medical radioIsotopes and beam Research
ENEA	Ente Nazionale per lo sviluppo dell'energia nucleare e le Energie alternative
ENIQ	European Network for Inspection Qualification
ENPOWER	Nuclear Plant Operation by Optimising WEld Repairs
ENUKRA	Embrittlement Assessment of Irradiated Pressure Vessel Steels
EORTC	European Organisation for Research and Treatment of Cancer
ESTRO	European Society for Therapeutic Radiology and Oncology
EXOTIC	EXtraction Of Tritium In Ceramics
FEA	Finite Element Analyses
FIMA	Fissionable (Heavy) Metallic Atoms
FP	Framework programme
FRAME	Fracture Mechanics Based Embrittlement Trend Curves for the Characterisation of Nuclear Pressure Vessel Materials
FZK	ForschungsZentrum Karlsruhe
FZJ	ForschungsZentrum Jülich
GT-MHR	Gas Turbine – Modular Helium
HABOG	Hoogradioactief Afval Behandelings- en Opslag Gebouw

HCPB	Helium-Cooled Pebble Bed
HEU	High Enriched Uranium
HFR	High Flux Reactor
HICU	High-fluence Irradiation of breeder Ceramics
HIDOBE	High Dose Beryllium Irradiation Rig
HIP	Hot Isostatic Pressing
HITHEX	HIgh Temperature Heat Exchanger
HTGR	High Temperature Gas Cooled Reactor
HTR-TN	High Temperature Reactor Technology Network
IAEA	International Atomic Energy Agency
IE	Institute for Energy
IHCP	Institute for Health and Consumer Protection
INET	Institute of Nuclear Energy Technology (of the Tsinghua University)
INTERWELD	Irradiation effects on the evolution of the microstructure, properties and residual stresses in the heat affected zone of stainless steel welds
IRI	Interfaculty Reactor Institute, University of Technology Delft (NL)
IRLA	Improvement of Residual Life Assessment of VVER Reactor Pressure Vessel
IRMM	Institute for Reference Materials and Measurements
ISIS	Institute for Systems, Informatics and Safety
ISO	International Organization for Standardization
ITER	International Thermonuclear Experimental Reactor
ITU	Institute for TransUranium Elements, Karlsruhe
JRC	Joint Research Centre
LCNDF	Large Component Neutron Diffraction Facility
LEU	Low Enriched Uranium
LYRA	Irradiation faciLitY for European network foR AMES
LOTUS	Irradiation at LOw TemperatUre of Martensitic Steel Specimens for Fusion Applications
LWR	Light Water Reactor
MANITU	MANet IrradiaTions for fUsion applications
MOX	Mixed Oxide
MTR	Materials Testing Reactor
NCT	Neutron Capture Therapy
NET	Network on NEutron Techniques

	Standardisation for Structural Integrity
NESC	Network for Evaluating Structural Components
NRG	Nuclear Research and consultancy Group
NTD	Neutron Transmutation Doping
PET	Position Emission Tomography
PIE	Post Irradiation Examination
PSF	Pool Side Facility
PWR	Pressurized Water Reactor
QA	Quality Assurance
RAMO	Power Ramp of MOX PWR fuel rods
REFA	REloadable Facility
RESTAND	Residual Stress Standard using Neutron Diffraction
RPV	Reactor Pressure Vessel
R&D	Research and Development
SANS	Small Angle Neutron Scattering
SCA	Shared Cost Actions
SIANC	Structural Integrity Assessment of Nuclear Components
SINAS	Simplified Na-Steel irradiation rig
SINEXT	INAS NEXT type
SMT	Standards, Measurements and Testing
SIWAS	Simplified Water-Steel irradiation
SOSIA	Sodium Specimens Irradiation
SPEECH	Safety of pressure equipment and components containing hydrogen
STRAIN	STRess relAxation in Inconel bolts under irradiatioN
SUMO	In-SodiUm Steel Mixed Specimens IrradiatiOn
TMS	Tritium Measuring Station
TRABANT	TRAnsmutation and Burning of ActiNides in a TRIOX
TRIO	Irradiation device with three thimbles
TRIOX	TRIO modified for irradiation of MOX fuels
TRU	TRansUranic
VAMAS	Versailles Agreement on Measurement and Standards
VTT	Technical Research Centre of Finland

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Abstract

The High Flux Reactor (HFR) of Petten is managed by the Institute for Energy (IE) of the EC - DG JRC and operated by NRG who are also responsible for commercial activities.

The HFR, operated at 45 MW of the tank-in-pool type, light water cooled and moderated, is one of the most powerful multi-purpose research reactors in the world and one of the world leaders in target irradiation for the production of medical radioisotopes.

2002 was a challenging year during which the HFR underwent an unscheduled full cycle shutdown and a safety audit but nevertheless also managed, amongst others, to:

- *operate 275 full-power days*
- *receive 150 visits involving a total of 955 people, which also included the Dutch Minister for Economic Affairs and a member of the US Nuclear Regulatory Commission.*
- *treat the last patient in the current BNCT trial*
- *underpin its strategic importance in the medical radioisotopes supply chain*
- *launch a European Network on Neutron Techniques Standardisation*

2002 was the third year of the four-year HFR Supplementary Programme.

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