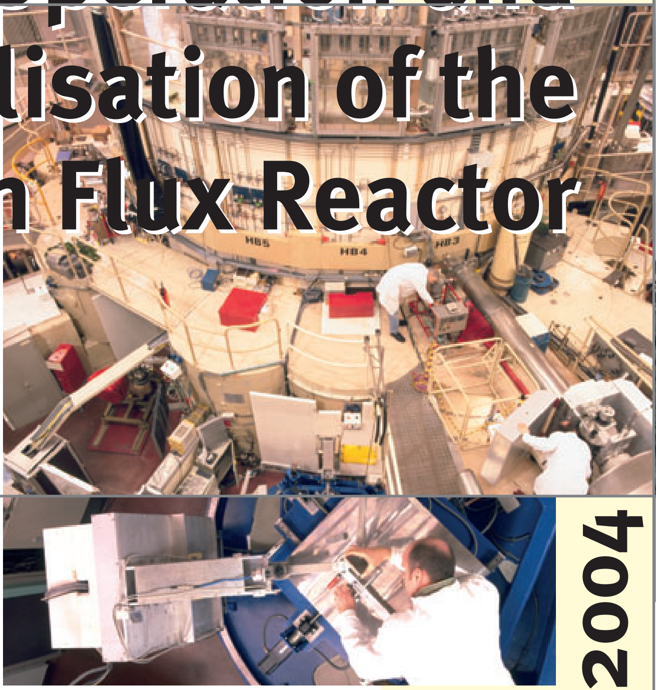
Operation and Utilisation of the High Flux Reactor



Annual Report 2004

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The Institute for Energy provides scientific and technical support for the conception, development, implementation and monitoring of community policies related to energy. Special emphasis is given to the security of energy supply and to sustainable and safe energy production.

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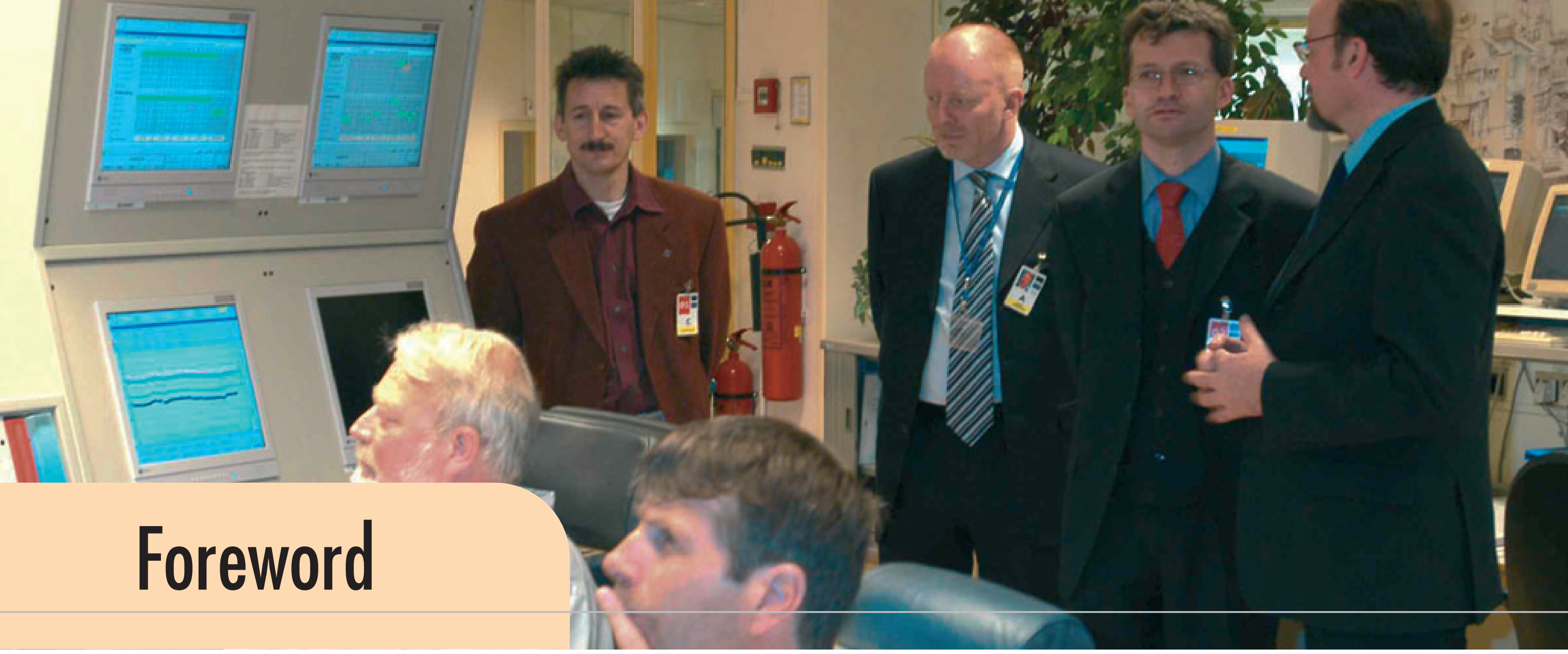


Foreword

The mission of the HFR is to perform research into neutron-material interaction in support of EU policies. The mission is deployed by optimal use of the reactor in the fields of:
- Nuclear safety of innovative reactors and existing reactors
- Health and environment
- Fundamental research

This includes participation in institutional and competitive activities as well as networking, training of young researchers and specific support towards new Member States.

2004 has been an important year in the deployment of the mission with the aim of strengthening the scientific output of the HFR in order to reinforce its scientific platform, improve its reputation and strengthen the anchoring of the European flag on the HFR.

In the context of the Dutch Presidency of the European Union, a timely seminar was held in 2004 at the Institute for Energy (IE), with the title: "The HFR: a key research reactor for Europe". The importance of the HFR was fully recognised during the seminar both for its scientific output and for its role in European health. The HFR currently produces over 50% of the European production of radioisotopes, an irreplaceable product in the field of nuclear medicine.

2004 was the first year of the 2004-2006 Supplementary Programme adopted by the European Council on 19th February 2004 and financed by The Netherlands and France. It is the last time that a Supplementary Programme will be used as the legal framework for the operation of the HFR. New mechanisms are being actively explored to secure operation beyond 2006.

An application for a new operating licence was submitted jointly by the JRC and NRG to the licensing authorities at the end of 2003, the result of more than 3 years work and with the total technical documentation amounting to 4450 pages. In 2004 the underlying technical documents, encompassing deterministic and probabilistic analyses, were finalized after the review of local, national and international experts. They constitute a state-of-the-art documentation package compliant with current international regulations.

2004 was also the year of the public debate on the new HFR licence as requested by the Dutch procedure, which provided a good occasion to present our high safety standards and our approach to safety culture.

In the framework of the new licence the HFR will progressively convert from high to low enriched uranium. During 2004 an intensive optimization of the conversion process has been conducted by means of reactor physics analyses through the evaluation of different fuel loading patterns. As a result the reduction in thermal neutron flux, a known disadvantage of the conversion, has been minimized to around 3%, thus assuring that the HFR will continue to be an attractive facility for the scientific and medical community.

A change in the management took place in 2004. From October 1st 2004 Marc Becquet left the management of the HFR Unit and moved to the JRC headquarters in Brussels as Head of the Unit Operational Safety and Security of Scientific Infrastructures. On the same date Roberto May, formerly in charge of the HFR new licence procedure, has been nominated acting Head of the HFR Unit.

Marc Becquet

Roberto May

Introduction

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

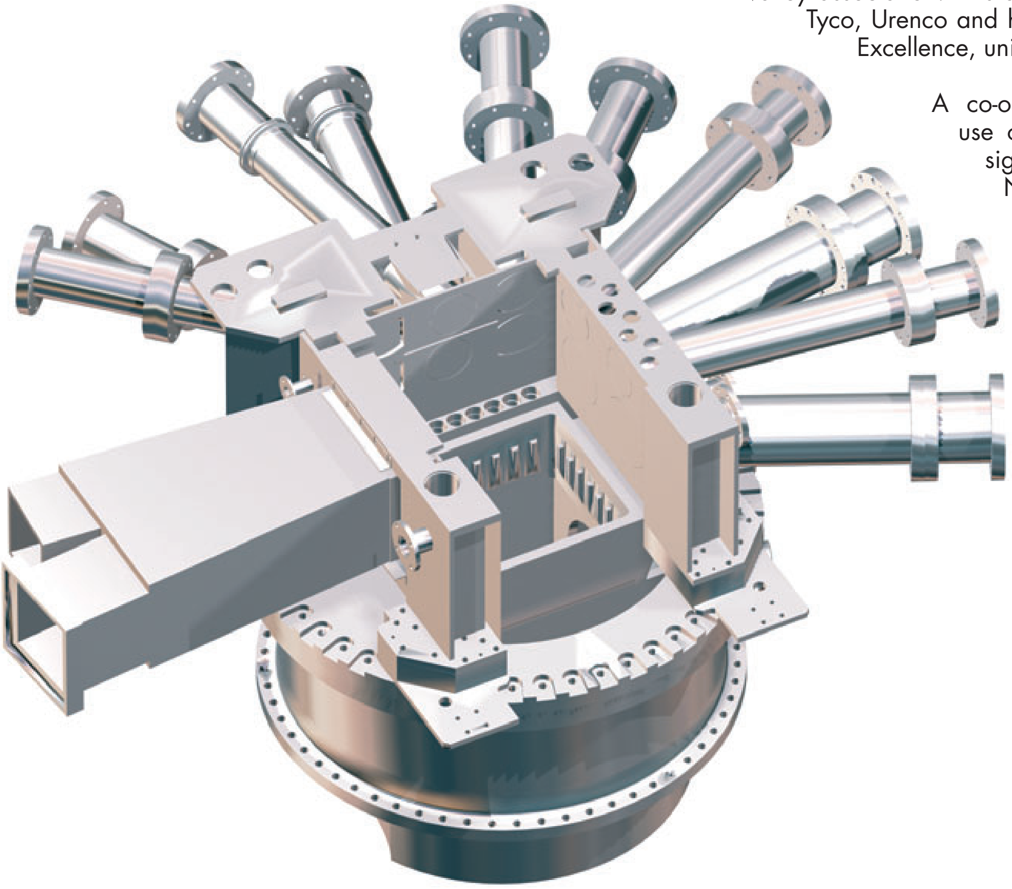
The HFR is of the tank-in-pool type, light water cooled and moderated and operated at 45 MW. In operation since 1961, and following a new vessel replacement in 1984, the HFR has a technical life beyond the year 2015.

The reactor provides a variety of irradiation facilities and possibilities in the reactor core, in the reflector region and in the poolside. Horizontal beam tubes are available for research with neutrons and gamma irradiation facilities are also available. Furthermore, excellently equipped hot cell laboratories on the Petten site provide virtually all envisaged post-irradiation examinations possibilities.

The close co-operation between JRC and NRG on all aspects of nuclear research and technology is essential to maintain the key position of the HFR amongst research reactors worldwide. This co-operation has led to a unique HFR structure, in which both organisations are involved. JRC is the owner of the plant (for a lease of 99 years) and the plant and budget manager; as well as, until the end of 2004, 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, since the 2000/2003 programme, manages the commercial activities around the reactor. As of 2005 and pending granting of the licence, NRG will become the licence holder

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, Urenco and hospitals leads to a Centre of Excellence, unique in Europe.

A co-operation agreement for the use of the HFR beam tubes was signed in 1999 between JRC, NRG and IRI Delft (Interfaculty Reactor Institute, Delft University of Technology, Delft, The Netherlands). This agreement allows free access of the IRI teams to the HFR beam tubes and promotes a fruitful collaboration in the technological improvement of the HFR beam tubes.



HFR: Reactor Management

HFR Operation and Related Services.

In 2004 the regular cycle pattern consisted of a scheduled number of 282 operation days and two maintenance periods of 22 and 24 days respectively. The reactor vessel In Service Inspection was performed during the summer maintenance period, 10 days of this period were dedicated for the In Service Inspection. In reality the HFR was in operation for 286 days (Figure 1). This corresponds to an actual availability of 101.4 % with respect to the originally scheduled operation plan. Nominal power has been 45 MW, except for a limited period during the summer, with a total energy production of approximately 12576 MWd, corresponding to a fuel consumption of about 16 kg U-235.

At the beginning of the reporting period, the HFR was in operation for the performance of cycle 03.12. Towards the end of the reporting period, the power distribution measurements for the FLUX 2004 programme and the annual reactor training programme have been carried out. During each scheduled end of a cycle shutdown was directly followed by activities performed in the framework of the regular HFR's operators training.

During cycle 04.05 the reactor power has been reduced several times below nominal power (≤42 MW) several times, to prevent exceeding of the allowed licensed outlet temperature of the secondary coolant (34°C).

Table 1 **2004 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)
2004		MWd	hrs	h.min	h.min	h.min	h.min	h.min	h.min	PD	Scram	Bq x E+11
01.01 - 12.01	03.12	525.63	280		280.00	00.17	280.17	07.43				5.0
13.01 - 09.02	04.01	1111.81	592	09.08	591.47	00.20	601.15	70.40	00.05	4	1	6.0
10.02 - 08.03	04.02	1138.70	592	04.42	603.10	02.00	609.52	62.03	00.05	4	1	6.0
09.03 - 30.03	Maintenance period							527.00				
31.03 - 26.04	04.03	1037.13	544	04.37	552.00		556.37	91.23				5.0
27.04 - 24.05	04.04	1128.12	592	01.53	604.00	00.18	606.11	65.37	00.12		2	8.0
25.05 - 22.06	04.05	939.77	592	306.42	273.47		580.29	71.31	44.00		2	6.0
23.06 - 19.07	04.06	1108.88	592	12.09	589.10	00.10	601.29	46.18	00.13		3	6.0
20.07 - 12.08	Maintenance period and ISI							576.00				
13.08 - 06.09	04.07	1041.83	592	144.59	431.14	00.16	576.29	23.27	00.04		1	11.0
07.09 - 04.10	04.08	1123.52	592	02.58	597.52		582.50	71.10				6.0
05.10 - 01.11	04.09	1112.34	592	02.41	591.57	02.51	597.29	75.31				6.0
02.11 - 29.11	04.10	1124.79	592	03.35	598.25	00.15	602.15	69.45				6.0
30.11 - 27.12	04.11	1109.12	592	03.22	587.38	16.48	607.48	63.12	01.00	4	1	6.0
28.12 - 31.12	05.01	74.54	24	03.34	38.25		41.59	54.01				
TOTAL :		12576.18	6768	500.20	6339.25	23.15	6863.00	1875.21	45.39	12	11	77
Percentage of total time in 2004 (8784 h) :				5.7	72.16	0.26	78.13	21.3	0.51			
Percentage of planned operating time (6768 h) :				7.4	93.67	0.34	101.4					

PD: Power decrease

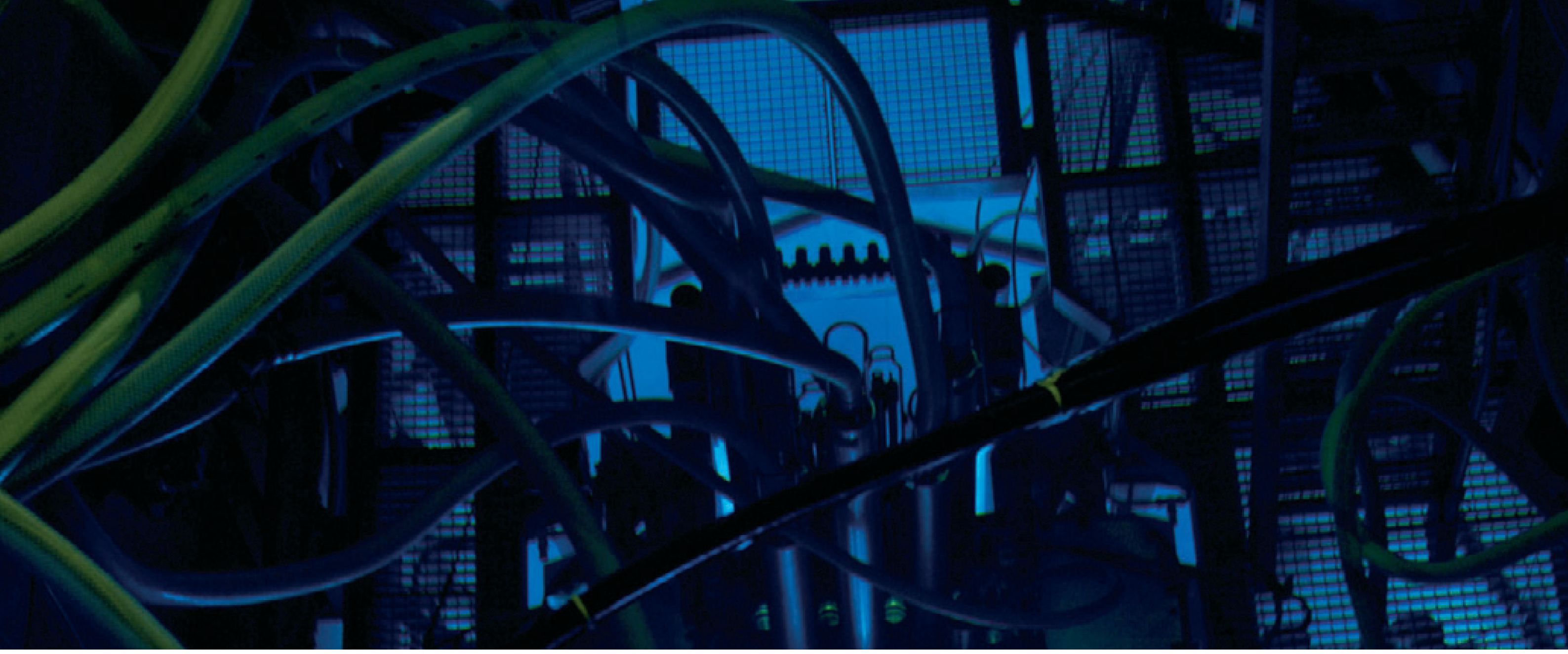


Figure 1 **HFR availability**

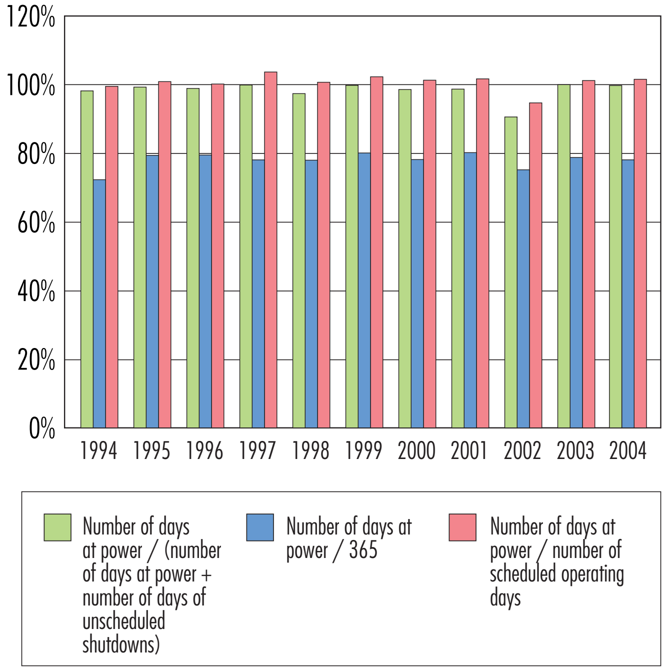
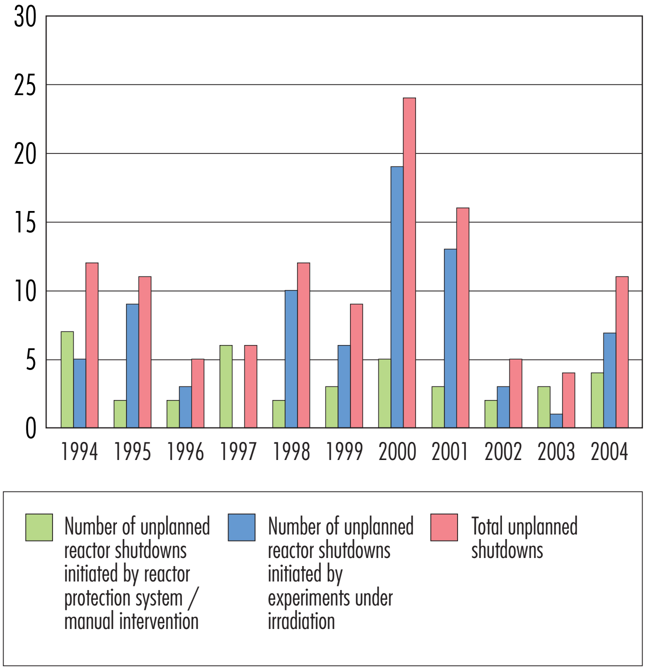


Figure 2 **HFR unscheduled shutdowns**



The 45 MW operation of this cycle was stopped on request of the major radiopharmaceutical suppliers, nearly one day later then originally planned. Shortly after the reactor start of cycle 04.07, the reactor power was stabilised at 37.5 MW to prevent again exceeding of the licensed outlet temperature. After receiving a new licence concerning the secondary coolant flow, the reactor power was increased to nominal power (≥ 42 MW).

The detailed operating characteristics for 2004 are given in Table 1. All details on power interruptions and power disturbances, which occurred in 2004, are given in Table 2. It shows that 11 scrams occurred (see Figure 2). Five of these scrams were due to human intervention, i.e. human error. Technical malfunctioning caused two other scrams, while the remaining four scrams were due to intervention by safety systems of the experimental devices.

In 2004 many people visited the reactor. Apart from the usual visits of international colleagues and relations in the medical world, the open day during each cycle, attracted many visitors. A total of 1333 people divided over 220 tours were guided through the facility.

DATE	CYCLE	TIME OF ACTION	RESTART OR POWER IN-CREASE	NOMINAL/ ORIGINAL POWER	ELAPSED TIME TO		DISTURBANCE CODE				REACTOR SYSTEM OR EXPERIMENT CODE	COMMENTS
					RESTART OR POWER INCREASE	NOMINAL/ ORIGINALPOWER	1	MW	2	3		
2004		hour	hour	hour	h.min	h.min						
22 Jan	04.01	14.39	14.46	14.47	00.07	00.08	AP	24	E	R	Experiment FUJI-01/02	For experimental reasons, the reactor power has to be decreased during handling of experiment FUJI-01/02 on the PSF.
23 Jan	04.01	21.50	22.00	22.03	00.10	00.13	MP	25	E	R	Experiment FUJI-01/02	For experimental reasons, the reactor power has to be decreased during handling of experiment FUJI-01/02 on the PSF.
24 Jan	04.01	17.29	17.29	17.30	00.00	00.01	AP	35.5	E	R	Experiment TIRO-02	During handling of experiment TIRO-02 a period of negative reactivity occurred.
31 Jan	04.01	10.53	10.56	10.58	00.03	00.05	MP	20	E	R	Experiment FUJI-01/02	For experimental reasons, the reactor power has to be decreased during handling of experiment FUJI-01/02 on the PSF.
01 Feb	04.01	19.56	20.01	20.12	00.05	00.16	AS	0	E	H	Experiment MYKONOS	During handling of experiment MYKONOS-06 on the PSF, the cooling water system of experiment MYKONOS-07 was slightly inhibited, resulting in a scram.
27 Feb	04.02	14.01	14.07	14.08	00.06	00.07	MP	25	E	R	Experiment FUJI-01/02	For experimental reasons, the reactor power has to be decreased during handling of experiment FUJI-01/02
28 Feb	04.02	22.27	22.40	22.41	00.13	00.14	MP	25	E	R	Experiment FUJI-01/02	For experimental reasons, the reactor power has to be decreased during handling of experiment FUJI-01/02 on the PSF.
29 Feb	04.02	17.21	18.12	18.14	00.51	00.53	MP	25.5	E	R	Experiment FUJI-01/02	For experimental reasons, the reactor power has to be decreased during handling of experiment FUJI-01/02 on the PSF.
03 Mar	04.02	05.22	05.35	05.37	00.13	00.15	MP	28	E	R	Experiment FUJI-01/02	For experimental reasons, the reactor power has to be decreased during handling of experiment FUJI-01/02 on the PSF.
03 Mar	04.02	06.03	06.08	06.18	00.05	00.15	AS	0	E	H	Experiment MIKONOS	During handling of experiment MYKONOS-07) on the PSF, the cooling water system of experiment MYKONOS-03 was slightly inhibited, resulting in a scram.
29 Apr	04.04	17.05	17.11	17.24	00.06	00.19	AS	0	E	H	Experiment MIKONOS	During disconnecting of the thermocouples of experiment MIKONOS-03 a plug of experiment MIKONOS-08 was accidently disconnected, resulting in a reactor scram.
04 May	04.04	19.09	19.15	19.25	00.06	00.16	AS	0	E	I	Experiment INCOMODO-01	During manipulations of experiment MIKONOS-06 the flow controller of INCOMODO-01 did not function correctly.
30 May	04.05	10.29					MS	0	A	E	Off-gas system	No integrator flow measurement of the Off-gas system present, the reactor was manually shut-down as prescribed in the Safety, Technical Specifications and regulations for the off gas quarterly dose.
01 Jun	04.05		06.23	07.18	43.54	44.49						
10 Jun	04.05	21.40	21.46	22.00	00.06	00.20	AS	0	E	I	Experiment INCOMODO-01	During manipulations of experiment MIKONOS-06, the coolant header pressure of experiment INCOMODO-01 exceeded the maximum setpoint, resulting in a reactor scram
04 Jul	04.06	01.04	01.08	01.22	00.04	00.18	AS	0	R	H	Safety channels	During manipulation of experiment TIRO-01 a period of positive reactivity occurred by which the setpoint of the safety channels was exceeded, resulting in a reactor scram.
04 Jul	04.06	17.41	17.46	18.08	00.05	00.27	AS	0	E	I	Experiment MIKONOS-07	During manipulation of experiment MIKONOS-07 the thermo couples TC2 and TC3 spontaneously exceeded the maximum setpoint, resulting in a reactor scram
12 Jul	04.06	17.43	17.47	18.00	00.04	00.17	AS	0	R	H	Safety channels	During manipulation of experiment INCOMODO-01, a period of positive reactity occurred by which the setpoint of the safety channels was exceeded, resulting in a reactor scram.
21 Aug	04.07	02.26	02.30	02.45	00.04	00.19	AS	0	R	I	Gasmonitor 2	During a fierce thunderstorm the maximum setpoint of gasmonitor 2 was spontaneously exceeded, resulting in a reactor scram
03 Dec	04.11	03.11	03.16	03.31	00.05	00.20	AS	0	E	I	Experiment THORIUM CYCLE-01	The adjusted mV settings indicated in the check-out procedure of experiment THORIUM CYCLE-01 were too low and not set at the correct value for 45 MW.
07 Dec	04.11	12.14	12.24	12.27	00.10	00.13	MP	25	E	S	Experiment FUJI-05/06	By working instruction the reactor power was reduced to 25 MW during manipulations with experiment FUJI-05/06 on the PSF.
09 Dec	04.11	14.23	14.27	14.30	00.04	00.07	MP	25	E	S	Experiment FUJI-05/06	By working instruction the reactor power was reduced to 25 MW during manipulations with experiment FUJI-05/06 on the PSF.
14 Dec	04.11	16.00	16.02	16.21	00.02	00.21	MP	25	E	S	Experiment FUJI-05/06	By working instruction the reactor power was reduced to 25 MW during manipulations with experiment FUJI-05/06 on the PSF.
18 Dec	04.11	21.00	21.04	21.13	00.04	00.13	MP	25	E	S	Experiment FUJI-05/06	By working instruction the reactor power was reduced to 25 MW during manipulations with experiment FUJI-05/06 on the PSF.

1. LEADING TO		**2. RELATED TO**		**3. CAUSE**			
- automatic shut-down	AS	- reactor	R	- scheduled	S	- mechanical	M
- manual shut-down	MS	- experiment	E	- requirements	R	- electrical	E
- automatic power decrease	AP	- auxiliary system	A	- instrumentation	I	- human	H
- manual power decrease	MP						

Table 2 **2004 full power interruptions of HFR**

Safety Culture

The safety culture enhancement programme 2004 has been coordinated by the Safety Culture Working Group (SCWG). The SCWG is a joint committee established by JRC, NRG and VROM-KFD in 2002. Its objective is "to assess and improve progressively the safety culture of the HFR organization". Every year since its establishment, the SCWG prepares an Annual Report summarizing its activities related to safety culture issues.

During 2004 the SCWG underwent modifications in its membership and in its tasks due to the development of new Terms of Reference. The group, at the end of 2004, is composed of two members from JRC and four members from NRG. The group met eight times in 2004.

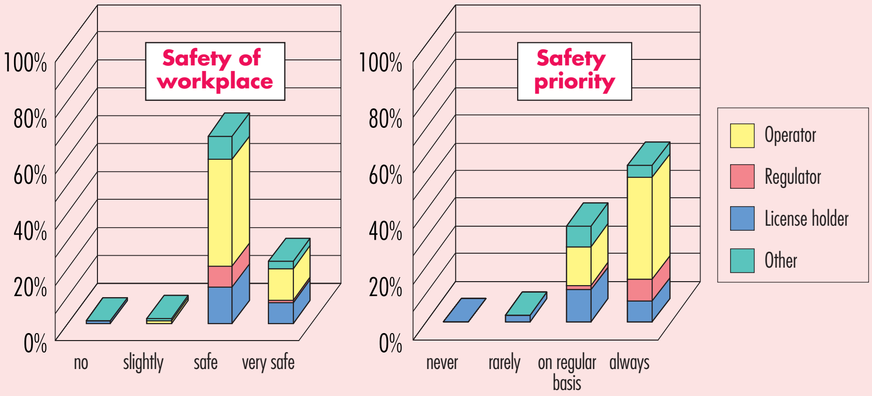
The basis for the development of SCWG actions for 2004 was the Table of Opportunities of Improvements, drawn from the Table of Strengths and Weaknesses developed after the Self Assessment Workshop in 2003. During the year, special focus was given to the improvement of communication about root cause analysis and to the analysis of the code of conduct developed by the NRG Human Resources Department. These actions were undertaken through the improvement team approach. Improvement Teams are teams composed of personnel responsible for improvement actions identified through surveys (Figure 3), self-assessment and interviews. Improvement teams give the possibility to personnel to be directly involved in safety culture issues and to openly propose improvement actions. The results have been very positive and welcomed by personnel. New improvement teams will be launched during 2005 on specific issues.

During the course of the year the exchange of information with the Reactor Safety Committee has improved and the need was felt to establish an interface between the two Committees.

Moreover, in the course of the year, Directors have been directly involved in the group's activities, through invitations to participate in group meetings.

Finally, the information on the SCWG activities has been included in newsletters to personnel in order to increase personnel awareness and involvement in safety culture issues. The development of a SCWG web site has been planned for 2005 with this aim.

Figure 3 **Example of Survey on Safety Perception, 2003**



MTR-2 container with HFR spent fuel transferred to HABOG

Fuel Cycle

Front end

During 2004, new fuel elements and new control rods have been inspected at the manufacturer's site and delivered on schedule. This was the last series of fuel elements and control rods containing high enriched uranium (HEU). The next series of fuel elements and control rods to be delivered in 2005 will contain low enriched uranium (LEU).

In 2004 the irradiation testing of a prototype LEU fuel element has been extended up to a burn-up of 75%. No abnormalities have been observed throughout the entire irradiation programme.

Back end

In 2004 one HFR spent fuel shipment to COVRA took place. Since 2000, this was the seventh shipment of HFR spent fuel in a MTR-2 container to COVRA and the second MTR-2 shipment that went directly to the HABOG facility for unloading and long-term storage. Furthermore all MTR-2 containers loaded with HFR spent fuel, which were in temporary storage at COVRA, have been transferred to HABOG and successfully unloaded.

New MTR-2 fuel basket ready for delivery

In 2004, new MTR-2 baskets and spare parts have been delivered and periodic testing of two MTR-2 containers has been performed successfully. In addition an application for a MTR-2 licence modification to include HFR spent fuel with a higher burn-up has been submitted to the German authorities.

Support has been provided to IRI Delft for transport of spent fuel from the Delft reactor to COVRA / HABOG by making available a MTR-2 container and transport equipment.

Finally a contract has been concluded with a transport company for shipment of HFR spent fuel to the United States. The shipments are to be performed in addition to the shipments to COVRA in the coming years.

Visits and Visitors

January	22	Visit of the Finnish Ambassador Mr. Pekka Säilä (second from left) to the HFR	①
April	21	Traditional annual visit of students of the 7th year (with option physics) of the European School visiting the HFR	
	23	Visit of municipal Zijpe	
October	27	Visit of Mr. John Hoover, Presidency Section Chief and US Embassy's Senior Advisor	②
	29	Visit of Member European Parliament, Mrs. Dorette Corby (second from the left)	③

Workshops and seminars

March	26-27	A two-day workshop for BNCT Drugs at European level. The workshop focussed on a more systematic drug development and on drug testing programme required in BNCT. The workshop was attended by 12 participants from institutes from France, Italy, Netherlands, Germany, Bulgaria, Czech Republic and Belgium	
October	04	Cancer Research at the JRC-Press Conference at VU Hospital Amsterdam; including a visit to the HFR	
December	1-2	NET-PECO workshop on Industrial R&D, Material Properties and strain/stress measurements, Neutron methods for engineering applications and Residual stress modelling.	
	16	In the context of the Dutch Presidency of the European Union, a timely seminar was held on at the Institute for Energy (IE) of the Joint Research Centre (JRC) of the European Commission at Petten, the Netherlands, with the title: "The HFR: a key research reactor for Europe". The seminar was organised for members of the European Commission's Joint Working Party on Research and Atomic Questions and members of the Atomic Questions Group, as well as a number of representatives from the Dutch Ministry of Economic Affairs and the Ministry of the Environment. A number of speakers, specialists in their area of expertise, were invited to present important topics on nuclear research, with a view to emphasising the importance of the HFR for the European research and radioisotope production needs of the future.	④

HFR: The Programmes

HFR as a Tool for European Programmes

EUROPEAN NETWORK AMES AND SAFELIFE

The SAFELIFE JRC Action provides an integrated approach to research and development on safety issues for plant life management of ageing nuclear power installations.

The Action focuses on establishing European best-practices for deterministic and risk-informed structural integrity assessment of key components considering all nuclear power plant (NPP) designs (both western and Russian). It exploits IE's competence in testing and characterisation of materials degradation (radiation embrittlement models development, thermal fatigue, stress corrosion cracking), structural mechanics, non-destructive testing & in-service inspection (ISI) qualification, neutron methods and advanced modelling techniques for residual stress analysis, as well as developing appropriate new areas expertise.

The activities in 2005 are organised following key primary circuit components: reactor pressure vessel, primary piping, core internals and their weldments.

In addition to these component-specific activities, further activities cover method development on more generic topics supporting decision making in life management, namely: uncertainty management, maintenance optimisation, human factors and safety culture issues, and risk-informed approaches. Active components are not covered by dedicated R&D work at present, however they are included in the scope of the maintenance optimisation tasks. SAFELIFE is starting a systematic approach to use the available capabilities to actively support advanced reactor materials research and advanced analysis (e.g. behaviour of materials under high loading rates due to 'external events').

SAFELIFE will continue to support European Networks and training activities within the frame of ERA. It will also continue a proactive policy for the integration of experts and organisations from new and member states and candidates countries in its activities.

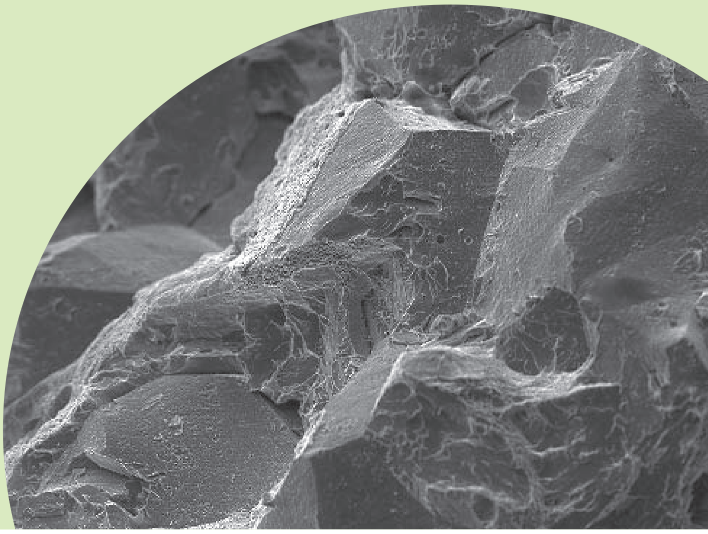
The strategic multi-annual goals of the Action are as follows:

- Provide a basis for harmonisation of European codes and standards on key primary components of light water reactors through developing and disseminating best practices
- Support long-term EU policy needs on PLIM and advanced reactor concept through enhancing JRC R&D competence and capabilities in nuclear safety technology
- Integration of R&D efforts in line with ERA principles by linking our R&D to utilities, manufacturers, R&D organisations and regulators through continuing exploitation of networks and collaborating with EC and international organisations
- Implementation of an effective plan for training, mobility, dissemination and knowledge management and development of competitive activities complementary to SAFELIFE objectives.

A series of tasks are directly addressing radiation embrittlement to improve understanding of reactor pressure vessel integrity issues, with emphasis on material characterisation, radiation embrittlement understanding, fracture toughness and application of probabilistic approaches for structural reliability analysis. and are mainly co-ordinated within the frame of the AMES European Network.

They include: irradiation in LYRA rig at HFR of different RPV steels, studies on non-destructive measurements of cladding radiation embrittlement (irradiated in the HFR), based on STEAM method, characterisation of material for IAEA CRP on Mn in high Ni steels (model alloys, model steels and realistic welds projects). Studies on inter-granular fracture, characterisation of materials for future vessels (Cr-Mo-V based alloys), support to large international projects like PERFECT and COVERS, etc.

Within the frame of the JRC Action SAFELIFE and the European Network AMES (Ageing Materials Evaluation and Studies) several activities and developments are ongoing after the successful series of irradiations in the AMES dedicated LYRA Irradiation Rig.
Significant progress towards a mechanism framework for understanding of irradiation embrittlement have been booked, in particular with regard to the synergism of Cu, P, Ni, Mn on radiation stability of steels. The research is targeted to both Russian-design and Western reactor pressure vessels.



Recent irradiations and results

PISA project, benefiting from three irradiation campaigns in the LYRA rig at the HFR, is producing important results in order to understand and quantify the phosphorus influence on steel ageing. Typical PWR, VVER, MAGNOX materials were studied; namely ferritic steels, C-Mn plate, the IAEA reference PWR plate JRQ, a VVER 1000 base metal 15Kh2NMFA, and a number of model alloys supplied by JRC-IE. In particular after the HFR irradiation it can be demonstrated that phosphorus segregation is not a critical worry in most technological power plant cases.

The results of the FRAME project, also with irradiation of samples representative of different reactor systems, both western and Russian-design, are supporting the validation for irradiated materials of novel methods for structural integrity; the master curve methodology in particular.

A new irradiation campaign in AMES dedicated in the LYRA rig was also prepared to study materials originating from WWER reactors in decommissioning in Germany.

Positron annihilation

A new laboratory to carry out investigations by positron annihilation methods has been commissioned. The rig is using at the moment a radio-active positron emitting source and the challenge is to create an intense positron beam converting neutrons and gamma radiation generated by the HFR into positrons. A new exploratory project, named HIPOS has been defined to study the feasibility of the rig at one of the HFR neutron beams.

Table 3 **Irradiations in Lyra within AMES**

LYRA I	REFEREE - Nuclear Electric	190 °C for $11.5 \cdot 10^{22}$ $n \cdot m^{-2}$
LYRA II	RESQUE / REFEREE	255 °C for $8.17 \cdot 10^{22}$ $n \cdot m^{-2}$
LYRA III	MODEL ALLOYS	270 °C for $6.11 \cdot 10^{22}$ $n \cdot m^{-2}$
LYRA IV	PISA I	200 °C for $5 \cdot 10^{22}$ $n \cdot m^{-2}$
LYRA V	FRAME	290 °C for $20 \cdot 10^{22}$ $n \cdot m^{-2}$
LYRA VI	PISA II	290 °C for $5 \cdot 10^{22}$ $n \cdot m^{-2}$
LYRA VII	PISA III	290 °C for $18 \cdot 10^{22}$ $n \cdot m^{-2}$

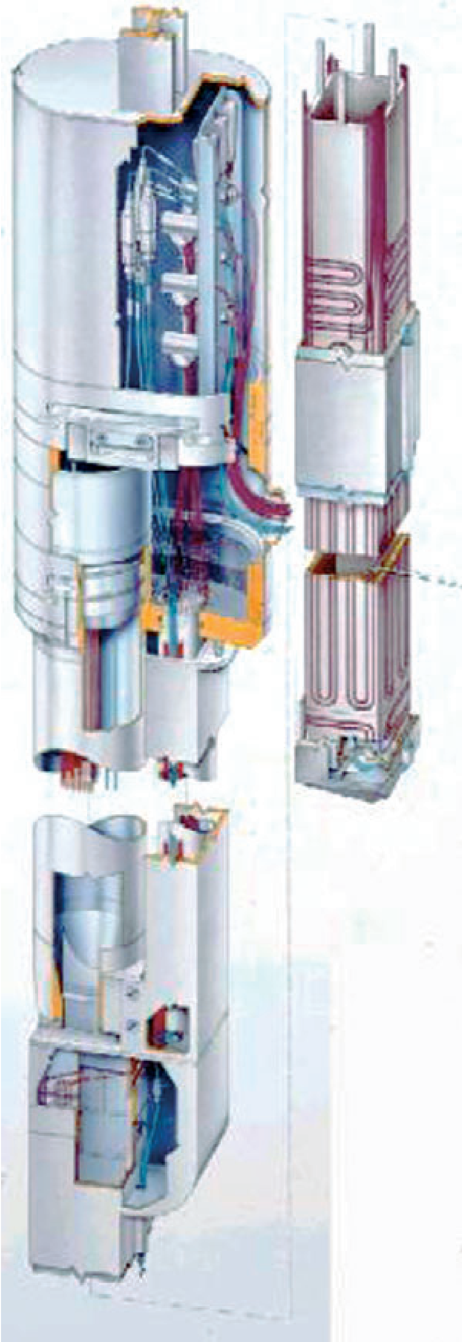


Figure 6:
NET Steering Committee Meeting,
IE-Petten, Dec. 2004

HIGH TEMPERATURE REACTOR TECHNOLOGY NETWORK - HTR-TN

Objectives

In response to growing interest worldwide, JRC initiated in 2000 the creation of HTR-TN with the main objective to recover, maintain and develop HTR technology from Europe and elsewhere with the ultimate goal of developing advanced HTR technologies. These activities support industry in the design of power plants complying with the various stringent requirements of sustainability, economic competitiveness, safety, waste production 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. Further information can be found at www.jrc.nl/htr-tn.

Achievements in 2004

The year 2004 was a particularly rich and active period for HTR-TN. JRC-IE continued operating this network, contributed to the related projects and provided significant technical input through both institutional and competitive actions.

Two Steering Committee meetings and eight meetings of the strategic task group were held with the 21 partners and observers from research, academia and industry. One main goal was to coordinate the running FP5 projects and to obtain consensus about the contents of the planned FP6 Integrated Project V/HTR-IP. The signature of the V/HTR-IP contract is expected for early 2005 for a duration of four years. Synergies with other FP6 projects on high temperature materials (ExtreMat) and nuclear hydrogen production could be maximized, and possible contributions to a number of Generation IV International Forum (GIF) projects were identified. In fact, much of the network's technical achievements can be used as input to the VHTR-related GIF projects. A strategic paper for the orientation of FP7 activities was equally drafted which proposes in particular strong cooperation with organizations owning or planning a new test reactor. Several HTR-TN members were appointed EU representatives in GIF project bodies and began with the definition and assignment of the work.

Thanks to the Euratom participation in GIF since summer 2003, a number of international relations could be revived or intensified. This includes in particular those countries with existing HTR technology development such as China, South Africa, Japan and, most recently, South Korea. A highlight was the 2nd International Conference on High Temperature Reactor Technology (HTR 2004), co-organized by HTR-TN and hosted by the Tsinghua University in Beijing, China, which operates the pebble bed HTR test reactor HTR-10.

NET – EUROPEAN NETWORK ON NEUTRON TECHNIQUES STANDARDISATION FOR STRUCTURAL INTEGRITY

The European Network NET was launched in May 2002 with 35 participating organizations from 11 European countries and South Korea. Its main objective is to support progress toward improved performance and safety of European energy production systems. To this end three task-groups (TG) have been established by the NET steering committee and the technical work within these is well in progress. By the end of 2004 about 40 organisations are participating in the Network, including eight organisations from the new member states, three organisations from candidate countries, one from Russia and one from S. Korea (Figure 6).

1. NET WORK PROGRAMME DEVELOPMENT AND EXECUTION

TG1 – Single Bead on Plate Weld

The purpose of this Task Group is to perform a thorough assessment of the 3-dimensional residual stress field around a single weld bead laid down on a small stainless steel plate. To achieve this objective, the NET partners have performed comprehensive experimental and numerical round robin campaigns. By the end of 2004 most partners have provided their results to the respective sub-task leaders and the work within this task group enters the reporting phase in 2005.

TG2 – Assessment of post-weld stress relief heat treatments

The experimental investigations of the post-weld heat treatments in ferritic steel letterbox repair welded specimens have commenced with a neutron diffraction campaign executed by JRC (Figure 7) and a series of X-ray diffraction tests performed by ENSAM, F. It was decided by the NET steering committee in 2004 that no numerical round robin would be launched for these specimens in view of the involved computing time and uncertainties in the results obtained from a full 3-dimensional analysis of this multi-pass welding process.

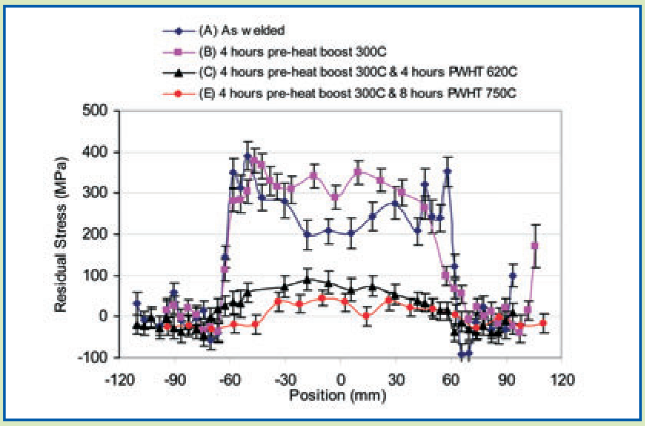


Figure 7 - Residual stresses measured in NET TG2 letterbox repair weld specimens after application of various post weld heat treatment intensities

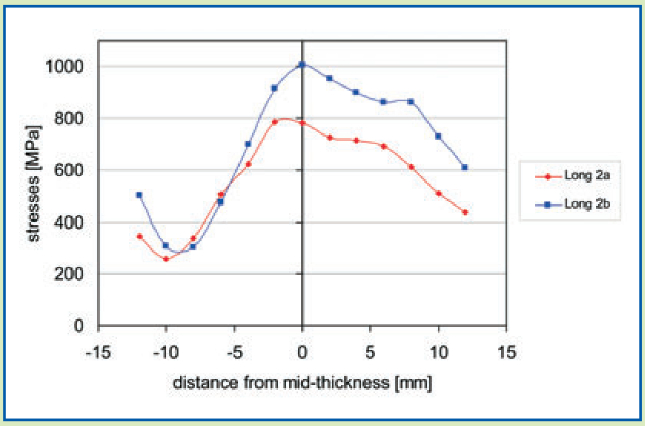


Figure 8 - Through-thickness distribution of welding longitudinal stresses in a letterbox repair weld in two ferritic steel plates – conventional welding process (2a) and non-conventional welding process (2b) - measured at the HFR/HB5 facility (ENPOWER)

Nevertheless, two partners decided to embark on a numerical analysis based on a problem definition that had already been prepared by the partners.

Within this TG a new experimental and numerical analysis campaign is now being developed that is more suitable for numerical analysis within the context of NET. This case will be an excavated steel plate, with its excavation filled with three longitudinal beads lying one on top of the other. The new exercise will be launched in the course of 2005. A supplier for specimens has already been identified amongst the NET partners.

TG3 – Assessment of effects of thermal ageing to cast duplex stainless steels

Based on agreed testing procedures, four facilities have supplied Small Angle Neutron Scattering data. The data has been presented at the NET steering committee meeting in June 2004 at Warsaw University of Technology, and some degree of agreement between the data could be shown. However, only one of the partners having provided the SANS data has been present at this meeting and no further discussion was therefore possible. As a consequence, TG3 is currently in a hibernating state. JRC is going to resume the work of this TG in the course of 2005, when the SANS facility at the HFR will be re-commissioned in its current set-up.

2. STANDARDIZATION ACTIVITIES

The joint ISO & CEN/TC138 AHG7 between 2001 and 2003 has drafted an international Technical Specification on a "Standard Test Method for Determining Residual Stresses by Neutron Diffraction". The final draft of the document has been submitted to the CEN & ISO Committees on Non-Destructive Testing for formal consideration in October 2003. In early 2004 the Two-Months-Inquiry was completed with only minor comments received on the document. In addition, the document has been translated into French and German and the final inquiry period has been launched. Adoption of the international Technical Specification by CEN and ISO is now expected for the first half of 2005.

3. NET RELATED SHARED COST ACTIVITIES

- ENPOWER - Assessment of novel methods for weld repair (Figure 8); on going
- HITHEX - Development of advanced CMCs for ultra HT heat exchangers; completed
- INTERWELD - Investigation of irradiation induced material changes in the HAZs of RPV welded internals; on going (Figure 9)

4. OTHER NET ACTIVITIES

Management of and participation in computational round robin and performance verification based on neutron diffraction data aimed at development of advanced numerical techniques for the prediction of residual stress in multi-pass DMW, by detailed simulation (3D, real time, bead by bead) of the welding process. (NESCIII/TG6)

Figure 9 - Transport and experiment container for residual stress analyses in irradiated stainless steel welds

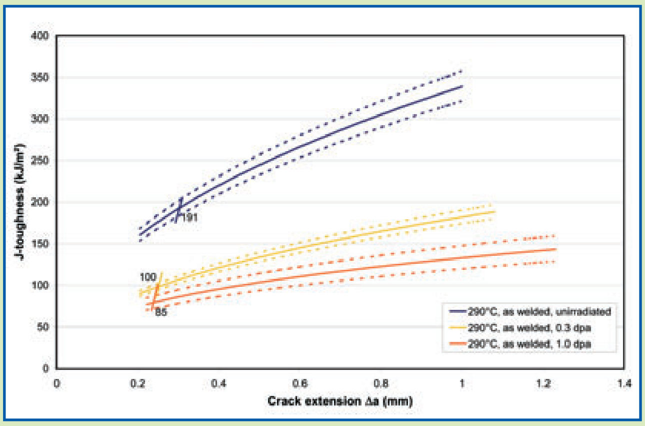


Figure 10 - Fracture toughness vs. crack extension for AISI type 347 austenitic stainless steel

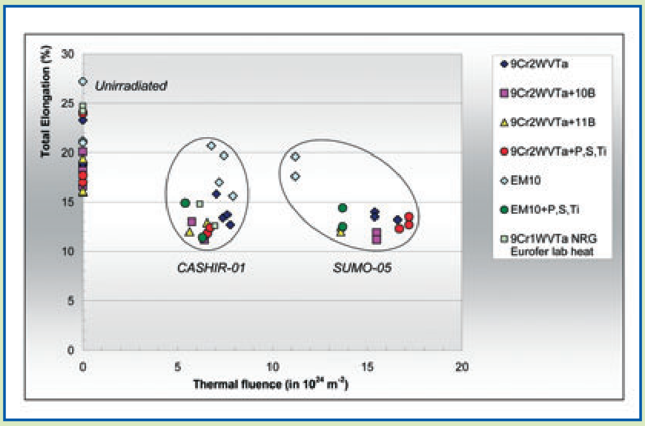


Figure 11 - Total elongation vs. thermal fluence for 250°C irradiated 9Cr materials

INTERWELD

Irradiation Assisted Stress Corrosion Cracking (IASCC) is a degradation phenomenon specific to core structural materials of Light Water Reactors (LWRs). Mainly neutron and gamma radiation influence the initiation and propagation of this not fully understood cracking process.

The main objective of the European INTERWELD project is to explain the neutron radiation induced changes in the welding heat affected zones of components that promote inter-granular cracking. This objective can be achieved by determining the relation between the development of several properties during irradiation and the stress corrosion cracking behaviour of welds relevant for components of a BWR.

Two irradiations with a target dose of 0.3 and 1.0 dpa (displacements per atom) were part of the project. The fracture toughness test results before and after both irradiations are shown in the Figure 10. As the crack initiation point is difficult to determine the engineering $J_{b10.2}$ has been indicated which is the fracture toughness after a small, defined crack extension.

SPIRE

Objectives

The SPIRE project was started in August 1999 to investigate irradiation and spallation effects on the structural integrity of 9Cr steels in an Accelerator Driven System (ADS). A commercially available martensitic steel, EM10, containing 9% Cr and 1% Mo has been investigated as well as some modified and purified steels like 9Cr2W0.2VTa. The steels have been irradiated up to 3 dpa nominal at 250°C in two irradiations – SUMO-05 and CASHIR-01. The latter design has a cadmium shield, which filters the thermal neutrons, giving a harder spectrum. Gaseous product generation has been simulated with ^{10}B-alloying and alloying with known detrimental elements like Ti, S and P has crudely approximated the spallation product generation.

Achievements 2004

Main outcomes are that EM10 has the best irradiation response up to the 3 dpa achieved in this study, closely followed by 9Cr2WVTa. There is no significant difference between the results from the shielded and unshielded irradiation, so within the variation in spectrum achieved, no effect has been demonstrated. In Figure 11 the total elongation is plotted versus the thermal fluence to investigate possible He effects on ductility, as the amount of transformed He from ^{10}B is proportional to the thermal fluence. Contaminated or 'doped' heats have demonstrated higher irradiation hardening than the clean and purified heats. No conclusive He effect could be demonstrated in irradiated ^{10}B doped 9Cr2WVTa for both spectra.

HFR: The Programmes

HFR as a Tool for Medical Applications

BORON NEUTRON CAPTURE THERAPY - BNCT

Introduction

BNCT is a "Disease Targeted Therapy", which is indicative of its inherent advantages over current advanced radiotherapy techniques applied in hospitals. Modern advanced radiotherapy techniques, such as the use of heavy ions and Intensity Modulated Radiotherapy (IMRT), can in principle produce a very precise dose distribution to a defined complex volume, i.e. a tumour in a very sensitive region. Unfortunately, even with these modern techniques, there are inherent problems, including: delivery of the dose to a volume, which includes healthy tissue; there is a dose build-up and fall-off around the tumour volume; image guidance techniques sometimes give contradictory information and finally a physician has to define the target volume, which may vary from physician to physician. In disease targeted therapy, the disease itself, and not the oncologist, defines the target, hence only diseased cells are damaged. From the principle point of view, BNCT offers to the clinician the opportunity to limit the damage to the tumour only. BNCT is based on the ability of the isotope 10B to capture thermal neutrons to produce two highly energetic particles, i.e. a helium (α particle) and lithium ion, which have path lengths in tissue roughly equal to the diameter of a single cell. Hence, when produced selectively in tumour cells, the particles can destroy the 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 have also started BNCT trials, namely: at the FiR-1 reactor Otaniemi (Finland); the R2-0 reactor Studsvik (Sweden); the LVR-15 reactor Rez (Czech Republic); and the TRIGA MkII reactor Pavia (Italy). BNCT trials outside Europe also continue: at the MIT reactor (USA), at 2 Japanese facilities, the JRR-4 reactor of JAERI and the KUR reactor at Kyoto and at the RA-6 reactor Bariloche (Argentina). Meanwhile, development towards BNCT clinical trials continues at the Birmingham University Accelerator (Dynamitron) UK, which will be the first BNCT facility at a non-reactor centre; at the THOR TRIGA reactor of Tsing Hua University at Tsinchu in Taiwan; at the Washington State University facility (animal studies only), and at the fast reactor of ENEA at Casaccia Italy. BNCT projects elsewhere are under consideration in many other countries, including Russia, Hungary, Bulgaria, South Korea, Thailand and China.
Meanwhile, at the IE Petten, a strong BNCT programme continues through the performance of clinical trials and carrying out research into various aspects of BNCT.

Competitive Activities

From previous Framework Programmes, three clinical trials on BNCT have been funded. These are:

- EORTC Protocol 11961: Post-operative treatment of glio*blastoma with BNCT at the Petten Irradiation Facility: Phase I Clinical Trial*
  This trial was closed in 2004, following the treatment of the last patient in 2003. The final reports on outcome, conclusions and recommendations is pending.
- *EORTC Protocol 11001: 10B-uptake in different tumours using the boron compounds BSH and BPA*
  This trial looks into the possible uptake of boron into different tumours, including thyroid cancer, head and neck cancer and liver metastases. If successful in terms of significant uptake of boron in the cancerous cells, patients with these type of tumours could become candidates for BNCT. Several patients have been entered into the study at Essen University hospital. JRC's role in this study is limited.
- *EORTC Protocol 11011: Early phase II study on BNCT in metastatic malignant melanoma using the boron carrier BPA*
  This trial has the objective to treat brain metastases of malignant melanoma using the boron compound, BPA. The trial has been prepared in common with the EORTC BNCT Group and the Harvard/MIT BNCT group in the USA. The trial was opened in 2004 and is reported on in more detail on page 17.

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, which along with some progress news, are as follows:

Development and maintenance of existing facility

The BNCT facility has been maintained and operated throughout the year following the preventative maintenance schemes written down for the facility. Various safety and maintenance procedures were performed including a shutdown/failure test of the compressors that maintain the argon in a liquid state in the beam tube. Tests showed that at full reactor power, the vacuum insulation around the argon system is maintained and that the argon remains liquid up to 6 hours after the compressor failure. As such, the safety procedures can be relaxed, which also reduces the likelihood of higher radiation doses to personnel during maintenance and operating periods. Furthermore, the therapy table underwent a weight test, and also had its operating mechanism renewed. A second pulsoxymeter was purchased, thereby acting as a reserve to the existing one, but also making it no longer necessary to take the existing one each time into the reactor building. The irradiation room was also re-painted.

A new Design and Safety Report presenting the updates and improvements made during the last 5 years, as well as an extra Chapter on Operating Experience, was prepared, presented to and approved by the Reactor Safety Committee.

Support to current on-going trials and new trials

JRC provided the technical and infrastructural support in the melanoma metastases trial (EORTC protocol 11011), which started during 2004. Support included treatment planning calculations, validation studies and patient positioning. New trials centred around the liver project, with progress being made in the design of the irradiation facility and setting-up the procedures to carry out this complex study (see page 18).

Beam dosimetry and treatment planning activities

A campaign of measurements and calculations started in 2003, were completed before mid-2004. This thorough re-calculation of the (radiation beam) source description, involving a variety of dosimetry measurements at the HFR, such as ionisation chambers, pn-diodes and activation foils, both in free beam and in cylindrical phantoms, yielded a new and improved source description of the neutron/gamma beam. The new source was then used in the treatment planning program NCTPlan, as part of its validation prior to its use in patient treatment for the melanoma trial. NCTPlan was introduced for this trial, due to its development by the MIT/Harvard Group, with whom JRC and Essen are collaborating in the melanoma metastases trial.

Figure 12 - Placing trays of vials containing cells loaded with boron-containing liposomes prior to irradiation at the BNCT facility

Figure 13 - Some of the members of the BNCT group during the treatment of a patient, indicating the intensity and number of staff, each with their own tasks and responsibilities, required to be present when performing patient treatments

Research activities, including:

- *Neutron beam improvement and design*
  New studies were performed using adjoint MCNP calculations, which form part of an on-going Ph.D. study.
- *Application to different types of tumours*
  The application of BNCT to other cancers, than brain cancer, as well as to non-cancerous diseases, supplements studies performed elsewhere in the BNCT community, where there is a need to demonstrate that BNCT is indeed a viable therapy for a variety of diseases. The liver project falls within this category.
- *Application to non-cancerous diseases - rheumatoid arthritis*
  A topic under investigation is the possible application of BNCT to treat rheumatoid arthritis, which affects 1-2% of the total population in Western countries. Rheumatoid arthritis is a disorder that affects joints and/or their surrounding tissues, for example strong cartilage degradation and osteoarthritis (both cartilage degradation and cartilage synthesis at undesired locations). This percentage is increasing nowadays due to ageing of the population. As such, studies into the use of BNCT to treat rheumatoid arthritis began at the HFR with 3 irradiation experiments in collaboration with the Dutch universities of Nijmegen and Delft. In order to achieve high concentrations of the boron-10 locally, liposomes have been found to be very attractive carriers. Initial results are promising and will be further developed in 2005.
- *Development of patient positioning devices*
  The current patient positioning frame has some drawbacks under certain beam directions, hence a new design is being developed, which will be tested during 2005.
- *Improvement of dosimetry*
  New measurements were performed using the large water phantom to answer questions on some discrepancies between calculations and previous measurements. Measurements in the free beam were also performed using a C(CO2) ionisation chamber, which appears to have advantages over the well-tested and utilised Mg(Ar) ionisation chamber. Further studies will be undertaken in 2005.

Start of a new trial on BNCT

- *EORTC Protocol 11011: Early phase II study on BNCT in metastatic malignant melanoma using the boron carrier BPA*
  Following an extended period (over 2 years) to resolve regulatory and approval procedures at the EORTC, the trial to treat melanoma metastases was opened in June 2004. The first patient was entered into the study in July 2004. A second patient was treated in November 2004. This trial is the first of its kind in Europe and was jointly prepared in collaboration with the BNCT Group at Harvard/MIT (USA). JRC performed the treatment planning using the code NCTPlan, ensured that the facility was fully operational and functioning, and coordinated the technical aspects of the treatment, including security, technical reporting and availability of required staff. Due to the fact that these patients have multiple metastases throughout the brain, a very homogeneous irradiation dose distribution is essential. As such, the two patients received 3 and 5 beams respectively on 2 consecutive days. The latter treatment was the first time in the BNCT world that such a treatment had taken place.
  During the treatment of the second patient, the 200th beam procedure on a patient at Petten was performed.
  Participating hospitals and institutes in the above trial are the Universities of Münster, Reims, Essen, VUmc Amsterdam, as well as JRC and NRG. The medical responsibility falls under the Project Coordinator, Prof.Dr.med. Wolfgang Sauerwein, and Study Coordinator, Dr. Andrea Wittig, of the Universitätsklinikum in Essen.

Figure 14: Patient undergoing gamma ray spectrometry measurements following BNCT

Figure 15 - Visit to the operating theatre during a liver transplantation at University Hospital Essen

Figure 16 - Liver surgeon demonstrating the form a liver transport takes and hence a possible irradiation configuration

- *Neutron activation of the patient – measurements using gamma ray spectroscopy*
  Following irradiation of a patient, radioactivity measurements are taken as part of the radiation protection procedure. Over 400 measurements have been taken over the years. Peak levels, i.e. at contact and directly after radiation, are of the order of 40-60 μSv/h, falling to less than 10 μSv/h 30-50 minutes after treatment. The average ambient dose equivalent in the first 2 hours at a distance of 2 m from the patient is of the order of 2.5 μSv.
  The ambient dose equivalent rate at 2 m distance from the patient's head at the earliest time of leaving the reactor centre (20 minutes after the end of treatment) is less than 1 μSv/h. Mainly driven from a scientific perspective, the spectrum of the emitted radiation has been investigated by gamma ray spectroscopy in order to identify the isotopes activated during treatment. Some of the patients underwent measurements directly following BNCT using a portable gamma-ray spectrometer. The spectrometry equipment or counting chain consists of:
  - EG&G HPGe detector (relative efficiency and FWHM at 1.33 MeV of Co-60: 12.7% and 1.71 keV, type: 26N-1602C)
  - EG&G 459 high voltage power supply
  - EG&G 572 amplifier
  - portable power supply
  - Canberra Accuspec interface, mounted in a Toshiba 3200 SX laptop computer

  Shortly after BNCT treatment (10-15 minutes), the patient sits on a chair, outside the reactor containment building (see Figure 14). The resulting spectrum indicates the signals from the various identified isotopes. The predominant isotopes were found to be ^{38}Cl, ^{49}Ca and ^{24}Na, which come from the naturally occurring elements in tissue. The initial activity is predominantly due to ^{49}Ca (from the cranium), whilst the remaining activity is predominantly due to ^{24}Na (longer half life). In one of the patients, the isotopes ^{198}Au and ^{116m}In could also be identified, which come from the neutron activation of elements used in the materials to make fillings for teeth.

Studies into the extra-corporal treatment of Liver cancer

Liver metastases are the most frequent kind of malignancy in Western countries (Europe and North America) and represent the most frequent site of recurrence of any primary tumour. Survival of patients with liver metastases depends primarily on the stage of the primary tumour. Nevertheless untreated patients invariably have a poor prognosis. In particular, as regards liver metastases from colorectal cancer, all the series reported in the last 30 years show that the median survival time of untreated patients is 6 to 12 months.
The optimization of surgical techniques in recent years has yielded a remarkable improvement in the results of hepatic resection. However for multiple lesions, which cannot be resected, the prognosis remains extremely poor. With this in mind, the group of Prof. Zonta and co-workers at Pavia Italy, pioneered the extra-corporal treatment of liver metastases by BNCT, i.e. the liver is removed in the operating theatre, taken to the reactor for BNCT, and then returned to the hospital for implantation back into the patient. On the basis of 2 patients treated in 2002, BNCT combined with adjuvant chemotherapy has been demonstrated to be very efficient in the treatment of multiple hepatic metastases from colorectal cancer.

As such, a project to perform a similar treatment at the BNCT facility at the HFR, in collaboration with the Departments of Radiotherapy and General Surgery at the University Hospital Essen, was started in 2003. During 2004, numerous progress meetings were held in Essen and Petten. A meeting in Essen involved visiting the operating theatre by the JRC project leader during a liver surgical operation (see Figure 15). One purpose of the meeting was to understand how a liver could be configured and handled in order to design a suitable carrier during irradiation (see Figure 16 until Figure 18). A meeting in Petten was also attended by the liver surgeon from Essen to obtain an impression of the BNCT facility.
With all this information in hand, an irradiation facility to hold the liver has been designed by Sander Nievaart (Ph. D. student, JRC/TU Delft). As a first proposal, the liver will be formed into a spheroid, placed into a special holder made from PMMA, which is then placed into an irradiation rig, primarily made of graphite (see Figure 19). The model used for the calculations in MCNP is shown in Figure 20. Results from the calculations have shown that the treatment can be realised when using the epithermal neutron beam at the HB11 BNCT facility. The Italian experience took place

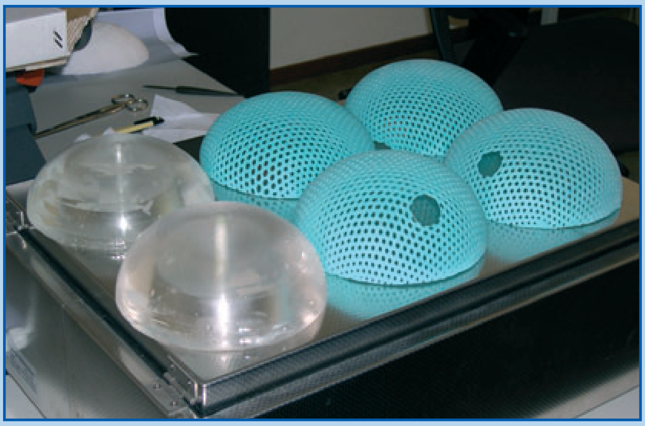


Figure 17 - Moulds and casts made at Petten to test possible liver container sizes

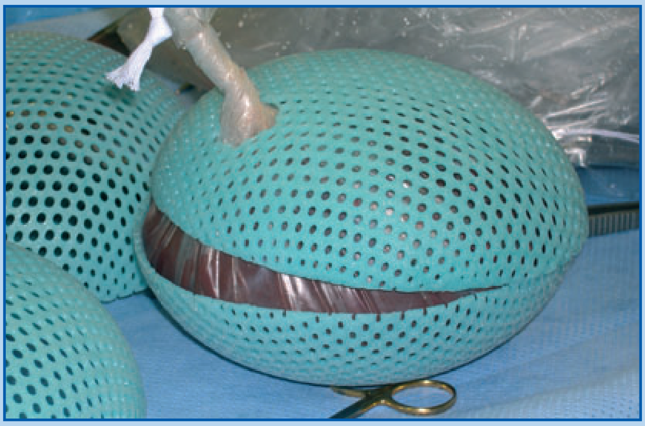
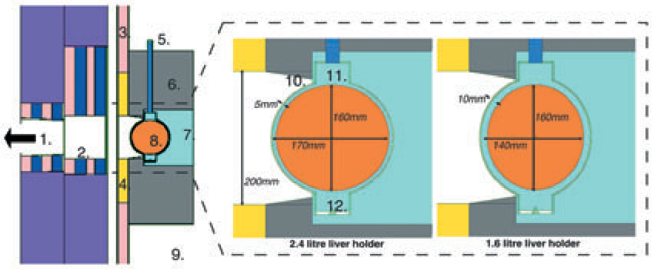


Figure 18 - Liver inside holder

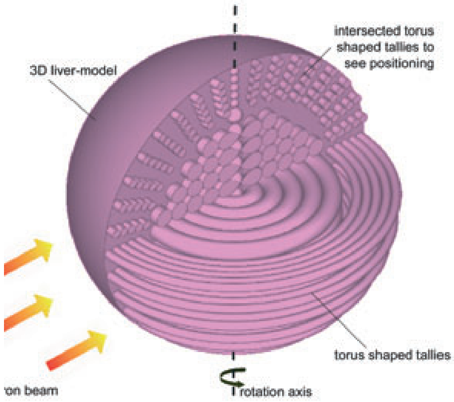
at a TRIGA reactor, in the thermal column, which has very different characteristics from the Petten facility.
Material to build the facility has been ordered. The rig will be built in 2005, in which measurements will be carried out to validate the design calculations. Thereafter, feasibility irradiations will be performed on the whole logistics of the study. The intention is to perform the first treatment towards the end of 2005.



1. Reactor core & filter 2. Beam shutter with no collimator installed 3. Wall containing boron 4. Wall containing lithium 5. Rotation axle liver container 6. Graphite reflector 7. PMMA container holder 8. PMMA container with liver 9. BNCT irradiation room 10. Graphite cone 11. Cylindrical part of PMMA holder for rotation and connecting the two halves (surrounded by Teflon O-ring) 12. like 11 but also centred on Teflon cone

Figure 19 (left) - Complete model of the liver irradiation rig, showing both sizes of livers considered

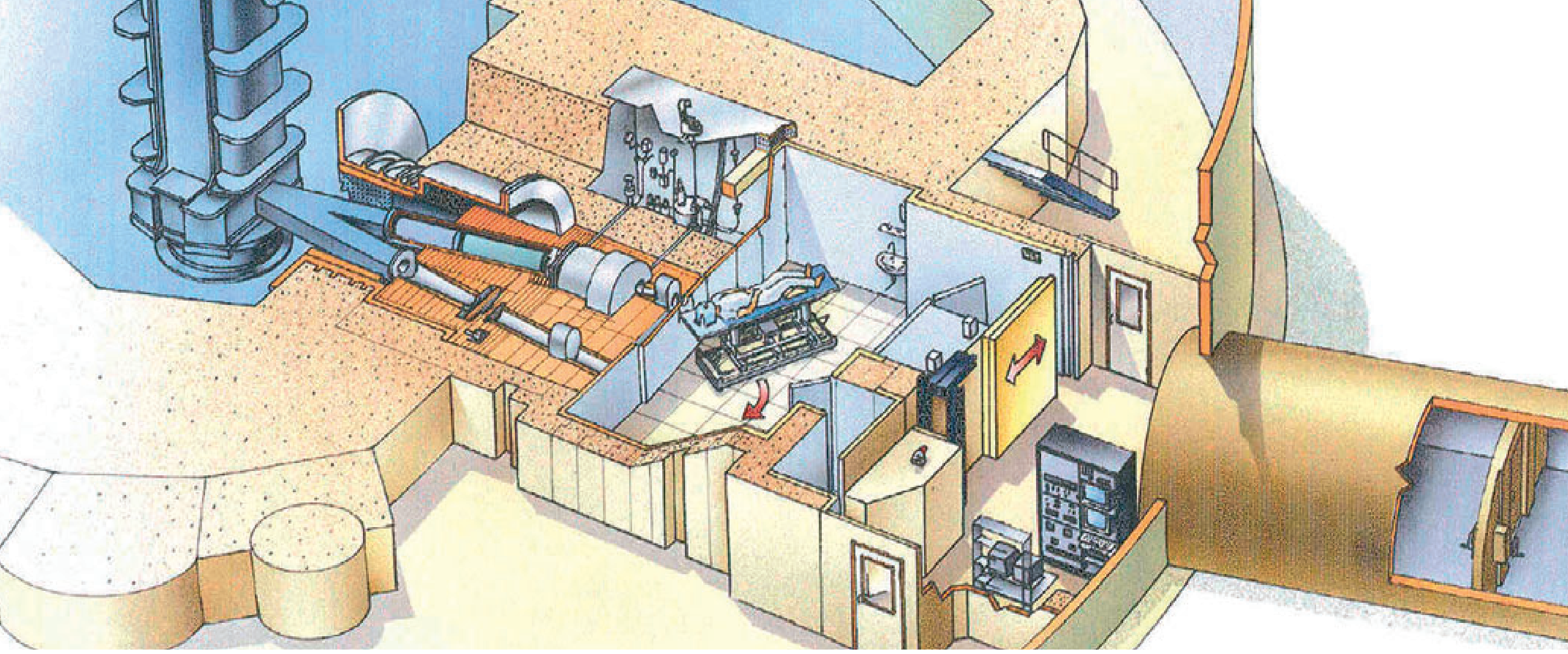
Figure 20 (right) - MCNP model of the liver as used in the design calculations



Missions, Symposia and Visitors

Numerous meetings were attended to discuss progress and collaborative actions, as well as organising and/or attending conferences and symposia. These included:

- European Workshop for BNCT Drugs: A two-day workshop was organised at Petten on 26-27 March 2004. A more systematic drug development and drug testing programme is required in BNCT. There are still only 2 boron compounds in clinical use in BNCT, despite little knowledge about mechanisms of accumulation and selectivity. New compounds, available only in mg quantities, stem from academic research and are not ready for *in vivo* tests. The meeting was attended by 12 participants from institutes from France, Italy, Netherlands, Germany, Bulgaria, Czech Republic and Belgium.
- The BNCT clinical trials are performed under the auspices of the EORTC. The annual meeting of all EORTC research groups, of which BNCT is one, was held in Brussels on 23rd April. R. Moss reported on the HFR and in particular its role as a test bed for current and future EORTC BNCT trials.
- 3-4 May, BNCT Workshop at National Tsing Hua University, Hsinchu, Taiwan. The BNCT action leader was invited to present the status of BNCT in Europe at the Workshop. At the University's research reactor, a new BNCT facility has been built and the official opening was held in combination with the workshop. A request for future collaboration to develop the project towards clinical trials was discussed.
- 4 October, Vrije University medical center, Amsterdam: organised by the JRC Brussels in collaboration with the VUmc as one of the events under the Dutch Presidency. Seminar title: "JRC support in the fight against cancer"
- 11-15 October, Eleventh International Congress on Neutron Capture Therapy, Boston, USA, where 7 presentations were given by JRC/Essen group. The biennial congress was attended by over 200 participants. BNCT is now applied to many different types of tumours. The most active country is Japan, with 5 different medical groups. The European situation has improved from 12 months ago, and trials are continuing in Sweden, Finland, as well as Petten, of course. The next congress is in Japan in October 2006.
- 16 December, Petten: seminar entitled "The HFR: a key research reactor for Europe". The seminar was organised for members of the European Commission's Joint Working Party on Research and Atomic Questions and members of the Atomic Questions Group, as well as a number of representatives from the Dutch Ministry of Economic Affairs and the Ministry of the Environment, each of which has responsibilities towards the HFR, with respect to licensing and regulatory affairs. Presentations were given by JRC staff on the HFR, as well as, Prof. Sauerwein, who presented the BNCT project.



EMIR

Background

The EMIR (European Network for Medical Radioisotopes and Beam Research) project was initiated in 2001 by the JRC-IE, building on HFR's position in the medical radioisotope production field, to identify and solve difficulties that constrain nuclear medicine and radiotherapy development in Europe and facilitate closer interdisciplinary collaboration. Partners in EMIR include the main European associations of medical radiation specialists, radiopharmaceutical radioisotope producers, nuclear research reactor institutions, research organisations and the JRC.

Work in 2004

Work focussed in 2004 on executing previous commitments, namely organising the 5th International Conference on Isotopes (5 ICI) and carrying out the radioisotope (RI) survey.
In addition, as a consequence of the decision in 2003 to orient EMIR as a Common Interest Group[1], various DGs were approached to assess their interest for the issue of medical isotopes and a Common Interest Group like EMIR to address that issue.
Due to the fact that medical isotopes were not yet on the agenda of DG policy-makers, it was decided that the EMIR activity did not fit any more in the JRC mission or work programme and it was thus decided in November 2004 to integrate EMIR into the NCT project by January 2005 and discontinue it fully by end June 2005, when all commitments would be completed.

RI Survey

The RI Survey started at the end of 2003 and consists of four parts:

1. *RI production capacity worldwide*
   (extended from the IAEA survey)
   contacts and interviews were carried out with IAEA; basic information is now available for finalising the report. Unfortunately, IAEA itself recognized that the response rate to their survey was quite low and that data received would not provide a full picture.

2a. *European demand for therapeutic RI*
   (extended from the EANM survey)
   a satisfactory response rate was achieved from most European countries allowing to define trends for most countries.

2b. *Inventory of medical guidelines for usage of therapeutic RI*
   Guidelines were gathered, allowing to show the discrepancy at the European level in the field.

3. *Status of R&D for medical RI*
   The response rate to formal and informal requests for discussion were quite low, showing the relative difficulty for gathering information in the field.

4. *Brachytherapy (BT) data*
   (extended from the ESTRO survey).
   Discussions are ongoing with ESTRO to get access to the BT survey.

The interim report of the RI Survey was delivered in June 2004; the final report is expected by mid 2005.

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(1) A Common Interest Group is a network with activities restricted to information and discussion platform, as opposed to a fully-fledged network which, not only includes the above activities but also aims at co-ordinating R&D projects and setting-up/maintaining a reference laboratory.

5ICI preparation

ICI is an international conference series focussing on the broad issue of isotopes at an international level, organised biennially by an *ad hoc* committee, independently from any formal body or organisation. 5ICI will take place from 24 to 29 April 2005 in the EC's Charlemagne Building in Brussels. The number of foreseen attendants is around 300 people. Although most participants are expected to come from the scientific community to ensure the quality of the scientific programme, special effort is made to attract policy-makers at all levels to promote the issue of radioisotopes, consistently with EMIR's original mission. Work on that matter in 2004 focussed on:

- Finalising the contacts databases for the mailings for 5ICI communications during January 2004. This contacts database was used for the mailing of the First Announcement (February 2004) and of the Second Announcement (December 2004)
- Setting-up a website (online: March 2004; updates in September and December 2004)
- Negotiating and signing a contract with the ESTRO (joint organiser). The contract was signed in May 2004
- Making progress in discussions with the Board of Trustees (BoT) of the International Isotopes Society (IIS) to provide a sustainable home for the ICI series and to unite the isotopes community. An agreement should be signed in by March 2005 between the international monitoring & steering committee of 5ICI and IIS's BoT
- Discussions and negotiations for the organisation of logistics aspects of 5ICI (gala dinner, welcome cocktail, accommodation, social tours, technical tours)
- Setting up a scientific committee to review contributions and define a scientific programme
- Ensuring financial support (sponsors and exhibitors) and high-level support

EMIR discontinuation

Contacts were taken in end-2004 with the various EMIR members to explain the withdrawal of the JRC from EMIR. An amendment to the network agreement should be signed by end April 2005, discontinuing the collaboration by 30 June 2005.

MEDICAL RADIOISOTOPE PRODUCTION

As in 2003, the level of isotope production from the HFR Petten in 2004 was extremely high, with the quantities of isotopes produced for medical applications growing further.

The overall importance of the HFR Petten in the worldwide supply of Key Medical Isotopes such as molybdenum-99 and strontium-89 was high and increased further. In the case of molybdenum-99, the strong market demand has led to a series of investments being made to increase the production capacity of the HFR Petten for this important isotope. These investments that include additional basin cooling capacity, as well as new specialist production facilities will allow the further expansion of production in 2005.

During 2004, the planned closure of both the FRJ-2 Reactor at Jülich, Germany and the R2 Reactor at Studsvik, Sweden were announced. These closures are scheduled for 2006 and 2005 respectively and both reactors play an active role in the production of isotopes for medical as well as industrial applications. These closures are anticipated to place further demands upon the HFR Petten for a number of different products and services. Medical isotope supply at the HFR Petten is likely to increase further as a result of these developments.

The supply of isotopes for new medical development and to support the early stages of Clinical Trial work using new and novel techniques continued strongly during 2004. A number of projects moved further down the development path, with some coming close to a regular supply phase and with formal Clinical Trials expected to start in 2005. These developments are generally subject to confidentiality agreements and as such cannot be fully reported at this stage of their development; but it is interesting to report that significant interest and activity is taking place in the area of therapeutic medical devices utilising isotopes, as well as in the development of radiopharmaceuticals.

The HFR Petten is one of the most important producers of isotopes for the worldwide medical market and it's position of importance continues to increase. The reliance of the Nuclear Medicine and Radiotherapy specialists for diagnostic and therapeutic isotopes is based upon the sound and reliable performance of the HFR Petten

HFR: The Programmes

HFR as a Tool for Fission Reactor Technology

In 2004, several activities were performed at the HFR in relation to fission R&D:

- HTR fuel and material irradiations at increased temperature and burn-up, structural material out-of-pile tests, and data management for HTR applications
- Irradiation of innovative fuel for the improvement of fuel cycles in LWRs, in particular with the objective of exploring the thorium cycle and of closing the uranium fuel cycle through the use of plutonium and the incineration of minor actinides

HIGH TEMPERATURE REACTOR R&D IN THE HFR

In the last years, two new test reactors were built in Japan (High Temperature Test Reactor) and China (HTR-10), while the US is equally planning a demonstration plant for the construction of which European companies are expected to tender. Significant progress was achieved in terms of fuel design and fuel cycle, structural materials, graphite and technology, and numerous other reactor concepts were developed worldwide. These use either compact fuel (US, Russia: Gas Turbine Modular Helium Reactor, initially designed for degrading weapons-grade plutonium) or pebble fuel (South Africa: Pebble Bed Modular Reactor). Either concept can rely on strong similarities with each other for the power plant technology. Feasibility studies for several advanced conceptual designs are conducted in a number of industrial companies, 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. The JRC-IE contribution is integrated in the related EU projects through technical contributions in the fields of fuel irradiations, out-of-pile material 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 at the HFR is maintained and constantly improved.

HTR Fuel Irradiations

Objectives

Two irradiation tests of low-enriched uranium fuel types in the HFR were further prepared and one was started. They aim at determining the limits of the fuel with respect to radioactive fission product release with increasing burn-up and at increased fuel temperature. 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:

- HFR-EU1: Irradiation of pebble type fuel produced by NUKEM (Germany) and by INET (Institute of Nuclear Energy Technology, China), with on-line fission gas release monitoring. Target burn-up is 21% Fissionable Heavy Metal Atoms (FIMA) for NUKEM pebbles and 16% FIMA for INET pebbles.
- HFR-EU1bis: Irradiation of pebble type fuel produced by NUKEM (Germany) at increased temperature with simplified fission gas release monitoring. Target burn-up is 16% FIMA.
- HFR-EU2: Irradiation of compact type fuel produced by General Atomics (USA) with on-line fission gas release monitoring. Target burn-up is 10% FIMA.

Within the GIF framework, discussions have equally started concerning the irradiation of South African fuel pebbles and Japanese fuel compacts.

Achievements in 2004

The HFR-EU1bis irradiation rig was prepared as well as its gas supply and analysis system. After finalization of the required documents, the irradiation was started in September and it was shown that the desired high fuel temperatures could be reached with sufficient homogeneity. During the start-up of the second irradiation cycle, an erroneous handling led to a leak between the two containments. After the verification of the safety of the installation, the irradiation could be pursued. The simplified fission gas release measurement proved to be reliable and consistent with earlier experiments. No fuel particle damage with increased fission gas release was observed so far.

The HFR-EU1 irradiation rig was assembled and commissioned. The on-line gas supply and analysis system (Sweep Loop facility) was equally assembled and installed in the HFR basement. The documentation of the irradiation rig is complete while the complexity of the Sweep Loop facility requires some more time. The irradiation is scheduled to start in the first half of 2005.

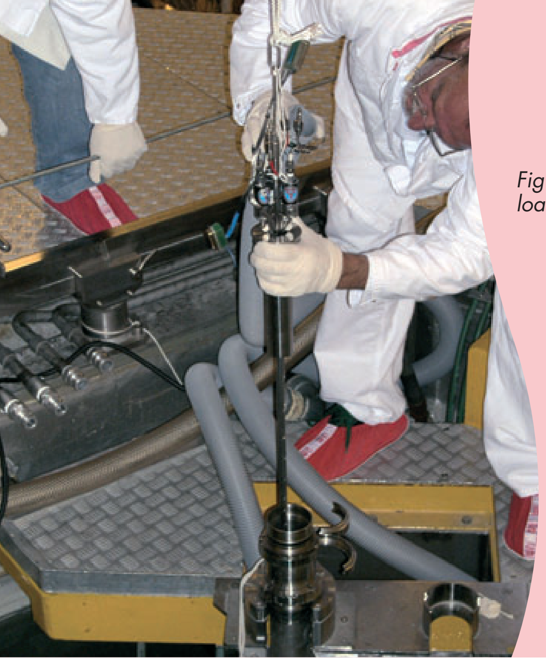


Figure 21 - HFR-EU1bis during loading in the HFR

Figure 23 - HFR-EU2 irradiation during repair

The HFR-EU2 irradiation rig was assembled. Due to failure of several thermocouples, they had to be replaced. Upon commissioning, several loose fuel particles were found in the capsule, which had to be removed. In November, the capsule was opened in presence of a General Atomics representative and the fuel compacts were found to be not in a state that would enable a meaningful operation of the experiment. Therefore, the project was suspended in December until the delivery of new fuel compacts.

HTR: Structural Material Out-of Pile Tests

Objectives

These tests aim at investigating the out-of-pile properties of high-temperature materials to be used for an HTR, such as pressure vessel material, control rods or ancillary components like the He turbine or heat exchangers. Out-of-pile material testing activities were prepared for the conventional part of an HTR power plant, in particular the helium turbine and helium-helium heat exchangers. The materials to be tested include metallic super-alloys or ceramic and fiber composite materials. The exposure in particular of the metals for longer periods of time to high temperatures and different helium chemistries may carburize or decarburize them, thus altering the mechanical properties.

Achievements in 2004

After the resolution of technical problems with the installation, the first carburized samples were produced, and production will be continued during 2005.

SCWR Material Out-of-Pile Tests

Objectives

JRC-IE is planning out-of-pile materials performance characterization for SCWR applications. In order to investigate the stress-corrosion cracking susceptibility of structural materials, two test benches for mechanical testing in supercritical water environment are under construction. The first one is a 20 kN universal mechanical test rig integrated into a recirculating water loop (36 MPa, 600°C) with full control of the water chemistry, while the other one is designed for the testing of miniaturized specimens for rapid screening of materials performance.

Achievements in 2004

The miniaturized specimen test rig was modified and put into operation, and preliminary tests were conducted to qualify and calibrate the installation. The recirculating water loop was designed and ordered, the delivery is expected for August 2005.

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.

Achievements in 2004

The activities in 2004 focused on maintaining the database and to prepare for its conversion to become "web-enabled". Due to the complexity of the required analysis of older reports, the process of feeding this database is expected to last for several years.

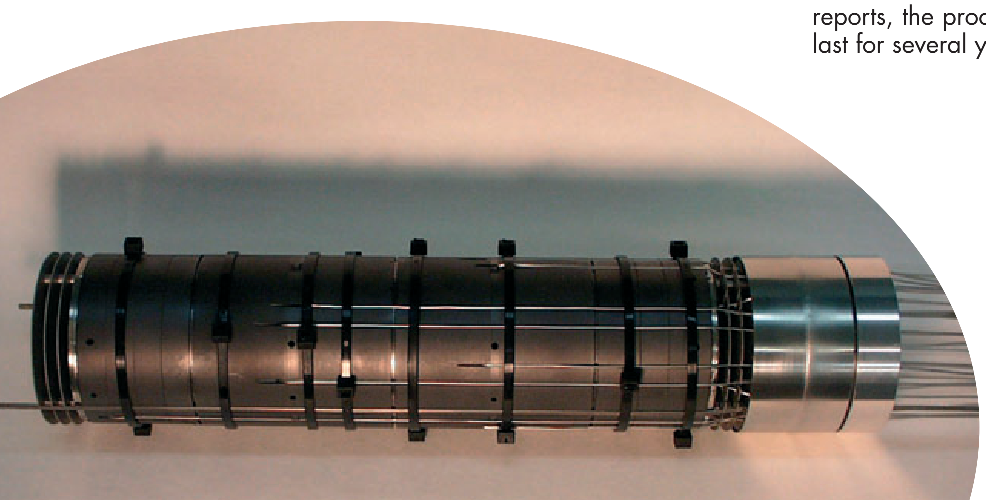


Figure 22 - HFR-EU1 during assembly

HTR Core structures graphites

Objectives
Extensive irradiation test programmes were performed more than a decade ago for earlier HTR projects. Today none of these earlier qualified graphites is produced commercially anymore, and most post-irradiation test facilities have become outdated. This has required the re-installation of qualification tools for HTR core structures graphite. NRG started this in 2002 within the HTR-M1 project.

Achievements in 2004
NRG has designed and built the INNOGRAPH-01 irradiation experiment and started irradiation in February 2004, with the target temperature of 750°C for a dose of 7 to 8 dpa (graphite). The rig contains about 200 specimens from eight different grades of potential candidates for a near future HTR. It is foreseen to re-load part of the loading and continue irradiation to a three times larger dose. Key properties of interest are dimensional stability, Young's modulus, thermal expansion and thermal conductivity. NRG has developed and installed the necessary post-irradiation test facilities and will perform a large measurement campaign in 2005. This programme forms the basis for expanding the test matrix within the follow-up project RAPHAEL IP.

HTR Vessel Material Irradiation and Post-Irradiation Tests

Objectives
One of the alternatives considered for HTR is the application of so-called hot-vessel. Modified 9Cr-steels, which could potentially be used up to 450°C. Thick-section weldments have been produced by Framatome ANP for reference, irradiation and post-irradiation testing of weldment and base metal.

Achievements in 2004
The irradiation of specimens cut from T91 weldment has been performed. Post-irradiation tensile behaviour and fracture toughness has been determined, and part of the in-cell creep testing could be completed. Longer term post-irradiation creep tests are prepared for FP6.

FUEL IRRADIATIONS FOR THE IMPROVEMENT OF FUEL CYCLES

MICROMOX

Objectives
Due to their intrinsic nature, high burn-ups are technically more difficult to achieve with (U,Pu)O_2 MOX fuels than with standard UO_2 fuel elements. This is due to the large amount of fission gas that is produced and released during irradiation with (U,Pu)O_2 materials and therefore, the build-up of higher internal pressure in the fuel rods, when compared to conventional UO_2 fuels. These higher pressures reduce the experimental margins relative to safety criteria and lead to a strict burn-up limitation by the safety authorities for this type of fuel. Reduction of gas release or rod internal pressure is however possible by either increasing dramatically the rod free volume, which is actually not compatible with the current fuel and reactor design or, in a more elegant way, by using a new generation of fuels with improved capabilities of gas retention.
The MICROMOX experiment is aimed at studying various MOX fuels with enhanced capability of fission gas retention. More specifically the objective of the project is to study the impact of MOX fuel microstructure on fission gas release at high burn-up and during transient conditions and to compare the performance of various MOX fuels with that of standard UO_2 fuels. In the MICROMOX experiment, eight individual fuel capsules are irradiated in a sample holder designed at the JRC-IE. The target materials are three experimental MOX fuels and one standard UO_2 material. Four capsules are equipped with a central thermocouple and a pressure transducer. Four other capsules are identically loaded but are not instrumented. All the capsules are filled with sodium to ensure thermal bonding. The expected burn-up at the end of irradiation is 55-60 MWd/kg_{HM}. The enrichment of the targets was chosen in such a way that such a burn-up is achieved after two years of irradiation (i.e. 25 HFR irradiation cycles).

Achievements 2004
The first irradiation cycle of MICROMOX (i.e. cycle 2003-10) started in October 2003 in position H8 of the HFR core. The MICROMOX experiment was loaded in the channel two of the south-oriented TRIO 131 rig together with the THORIUM-CYCLE experiment, which was previously loaded in channel 1.

Following a reactor scram, which occurred on 3rd March 2004, several oscillations/changes have been observed in the temperature and pressures readings of the MICROMOX experiment. After having analysed all the possible failure scenarios, it has been concluded that a failure of the cladding or the capillary tube of capsule 3 inside the first containment has occurred and that fission gases have been released in the first containment and that Na has likely entered the capsule. Since this occurrence did not have any consequence both for the safety of the experiment and the safe operation of the HFR the MICROMOX irradiation has been continued until the end of the cycle 2004-02 (i.e. until 8th March 2004). However, in order to better understand the actual status of the MICROMOX experiment, the irradiation was suspended at the end of cycle 2004-02 and an additional neutron radiography of the TRIO rig was taken during cycle 2004-03. The analysis of the radiographic pictures lead to the conclusion that six-out-of-eight fuel capsules and related instrumentation have been displaced over distances up to a few centimetres. The analysis concluded also that the sample holder did not suffer any major damage leading to any concern for both the safety of the experiment and the safe operation of the HFR and therefore, the continuation of the MICROMOX irradiation has been authorised for the whole duration of the experiment in absence of new and unexpected accidental events. The MICROMOX irradiation was restarted in cycle 2004-05 and, at the end of 2004, had accumulated 11 irradiation cycles.

THORIUM-CYCLE

Objectives

The use of thorium offers challenging options for nuclear waste reduction, both at the back end and at the front end. Thorium, a naturally occurring material, is a fertile material which can be converted into ^{233}U in a nuclear reactor. The subsequent fission of ^{233}U has the advantage that less of the radiotoxic actinides such as Np, Pu, Am and Cm are produced, compared to the conventional cycle, where ^{235}U is used as a fuel. An interesting application of the THORIUM-CYCLE is the once-through thorium-assisted Pu-burning. In $(Th,Pu)O_2$ fuels, the Pu destruction rate can be about twice higher than in $(U,Pu)O_2$ fuels. Since the data for the $(Th,Pu)O_2$ are scarce, irradiation of this fuel type was necessary.

The general objective of the THORIUM-CYCLE experiment is to investigate the behaviour of such a type of material at up to high burn-up (i.e. higher than 50 GWd/t_{HM}). In the THORIUM-CYCLE irradiation experiment, four target materials have been irradiated , namely: $(Th,Pu)O_2$, $(U,Pu)O_2$, UO_2 and ThO_2. All the capsules were equipped with central thermocouples. Similarly to the MICROMOX experiment, all the capsules are filled with sodium to ensure thermal bonding.

Achievements 2004

At the end of 2004 (i.e. cycle 2004-11), the THORIUM-CYCLE experiment had completed the planned 25 irradiation cycles, corresponding to a total irradiation time of 625 full power days. It was originally planned, that this time would have been enough to reach the targeted burn-up. However, after checking that assumption, it appeared, that the burn-up achieved after 25 irradiation cycles was about 10% lower than the planned one. The main reason for the unexpected low burn-up was the unanticipated presence of two Low Enriched Uranium (LEU) fuel elements in the HFR irradiation positions H3/H7 (i.e. PROFEET LC005 and CHIP LCC01) close to the irradiation position of the THORIUM-CYCLE experiment. Therefore, in order to be able to reach the scientific goals of the project an extra irradiation time of three HFR cycles was required.

Since the targeted burn-up had not been reached after 25 irradiation cycles, the continuation of the irradiation was still covered by the computations and safety assessment performed in the Design and Safety Report and the Addendum to the Design and Safety Report. In general, the safety margins of the THORIUM-CYCLE experiment were large and the temperatures of the experiment were monitored extensively. A scram alarm was connected to several thermocouples to check the sodium level. Therefore, there was no safety hazard associated with the continuation of the experiment, and the computations and assumptions of the Design and Safety Report were still valid. Therefore, it has been decided to continue the THORIUM-CYCLE experiment for three additional irradiation cycles, starting with cycle 2005-02.

During the whole irradiation, a series of neutron radiographies have been made to check the actual condition of the sample holder and of the fuel pins.

Figure 25 - Sweep Loop facility installed in the HFR basement

HELIOS

Objectives

The HELIOS irradiation (formerly EFTTRA-T5) was originally planned in the frame of the EFTTRA co-operation to investigate the behaviour of minor actinides and long-lived fission products under irradiation in the frame of transmutation studies.

Currently the HELIOS irradiation is part of a comprehensive Integrated Project (IP) on Partitioning and Transmutation (i.e. the EUROTRANS Project) which has been finally approved, as a part of the 6th Framework Programme, by the European Commission at the end of 2004.

The main objective of the HELIOS irradiation is to obtain data on the in-pile behaviour of the main candidate materials for the transmutation of transuranium elements (i.e. Pu and Am in the present programme). The following fuel pins shall be irradiated in the HFR as a part of the HELIOS irradiation:

- Pin 1: $Am_2Zr_2O_7$+MgO
- Pin 2: $(AmZr,Y)O_2$
- Pin 3 : $(Am,Pu,Zr,Y)O_2$
- Pin 4: $(Zr,Am,Y)O_2$+Mo
- Pin 5: $(Pu,Am)O_2$+Mo

The JRC-IE is involved in:

- Co-ordination of the design of the irradiation experiment
- Fabrication of the sample holder
- Assembly and commissioning of the experiment
- Project engineering of the irradiation experiment

The start of the irradiation is foreseen in Spring 2007 and will last 10 irradiation cycles.

Achievements 2004

Since the EUROTRANS project was approved only at the end of 2004 and will now start in April 2005, the activities carried out in 2004 were mainly devoted to the pre-design of the experiment in close co-operation with the international partners (i.e. CEA, NRG, JRC-ITU and EdF) involved in the project.

TRABANT-02

The first phase of the experiment, sponsored by FZK and ITU Karlsruhe, in which two mixed oxide fuel pins with a high Pu (40-45%) content and with the aim to assess the irradiation behaviour of such fuel pins up to medium burn-up, was completed in 2002. The second phase involves the irradiation of a third fuel pin, composed of two separate fuel pins, one on top of the other, both containing 0.9 g/cm^3 of plutonium, incorporated into an yttria-stabilised zirconia phase, $(Zr,Y,Pu)O_{2-x}$, with one composite fuel type mixed with stainless steel powder acting as the fuel matrix. However, due to delays in the manufacturing process, as well as, considerable delays in the internal procedures at Petten, regarding approval of a new Design and Safety Report, the second phase could not be started during 2004. A start in early 2005 is now anticipated. The irradiation will then continue for another nine reactor cycles.

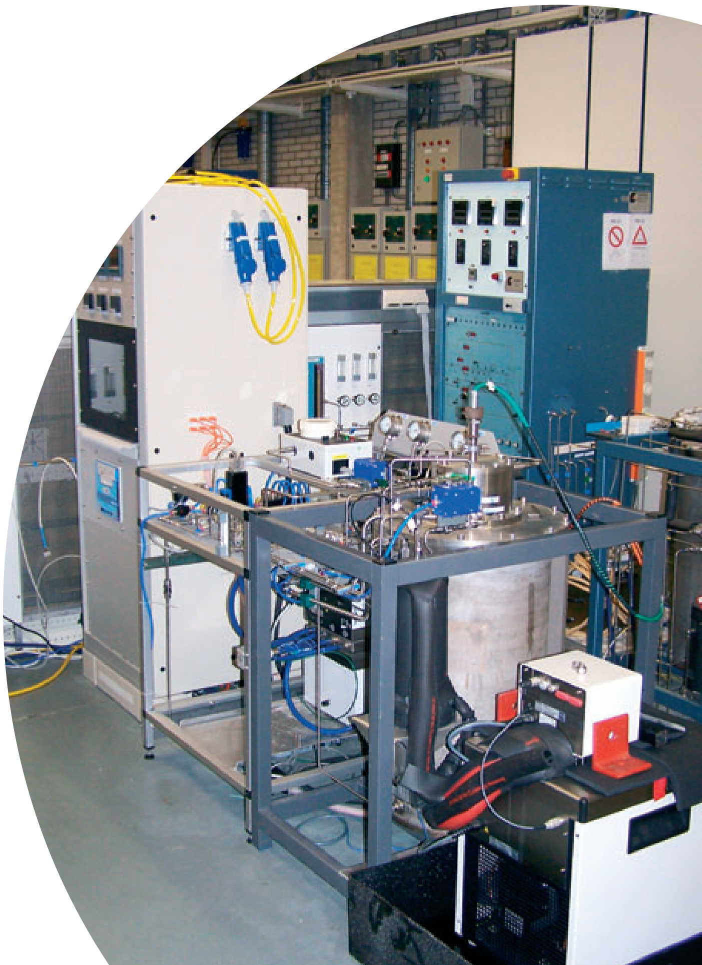
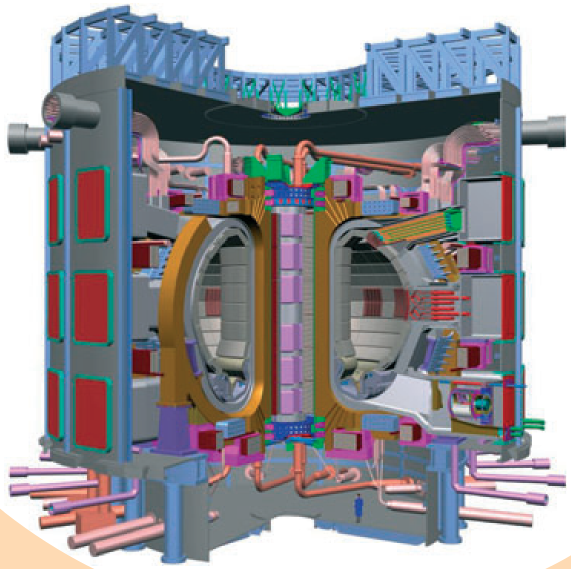


Figure 24 - Installation for carburization/decarburization of high temperature materials



HFR: The Programmes

HFR as a Tool for Fusion Reactor Technology

Effort for the development of electricity generation from fusion started in the middle of the last century and aims 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 orders 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, using deuterium and tritium as fuel, is designed to produce 500 thermal Megawatts during pulses lasting at least 1000 seconds and expected to operate in the next decade.

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 have recently joined the initiative, and others may do in the near future. The important role of the EU in the ITER initiative is also reflected in the HFR programme carried out by NRG: HFR's high versatility provides it 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 in-pile instrumentation for the operation of the test blanket modules. In this way the HFR provides valuable in-pile process data for blanket operations in ITER.

ITER vessel/in-vessel

It is anticipated that the segments of the vacuum vessel wall of ITER may have to be repaired or sections may need to be replaced. Welding of fresh materials to neutron-irradiated segments is then unavoidable. Post-irradiation welding following neutron irradiation in the HFR will provide designers with information on the potential of this approach and the resulting integrity of the welds.

The study on the feasibility and practicality of demonstrating the reweldability of vessel components from ITER has been completed. The study concludes that the best way to do this is to have a combined approach, based upon the demonstration of reweldability of components irradiated in a MTR followed by a demonstration of the reweldability of witness specimens recovered from the ITER machine just prior to the actual rewelding operation.

In support of ITER re-welding activities, stainless steel specimens of 5 to10 mm thickness were irradiated in the HFR pool-side facility and then welded under various constraint conditions. Specimens are now investigated for micro-structural features in the HFR hot-cell laboratories. It should bring further information on the influence of helium content.

Presently, bolting of shield modules to the ITER vessel structure is envisaged. These bolts are exposed to weak neutron fluxes; such exposure might however be sufficiently strong to affect their pre-stressed condition. Post-irradiation testing was performed for high strength materials selected for bolting applications (such as Alloy 625+ and PH-13-08-Mo). Specimens were pre-stressed bolts and bent strips, irradiated to nominal 0.5, 1.0 and 2.0 displacements per atom (dpa) at 300°C in HFR in 2003/4. Due to the high stack length a large flux variation could be accounted for and made the actual doses range from 0.27 to 2.66 dpa.

Of the two candidate materials PH13-8Mo and Alloy 625+, the former shows more favourable stress relaxation and strength capabilities under neutron irradiation for the application as bolt material in ITER. The alloy 625+ shows faster stress relaxation than expected, and suffers from irradiation softening.

In the same irradiation series STROBO-03/04/05, each centre column contained eight fatigue specimens of Alloy 625+. At the time of irradiation, Alloy 625+ it was the main candidate for the bolt material for fixing the first wall panels to the shielding modules in ITER.

During the tensile testing of stress relaxation specimens in the aforementioned STROBO irradiations, it became apparent that the yield stress was decreasing with irradiation dose. This had to be taken into account in fatigue testing. The irradiated specimens will be tested in 2005 at stress levels depending on the results of the reference tests.

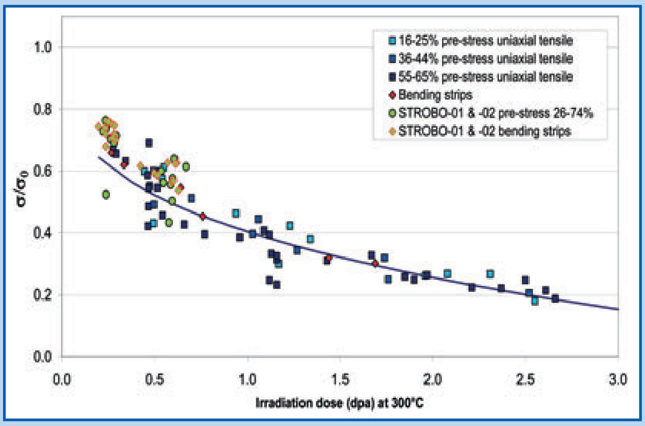


Figure 27 - Stress relaxation versus irradiation dose for Alloy 625+

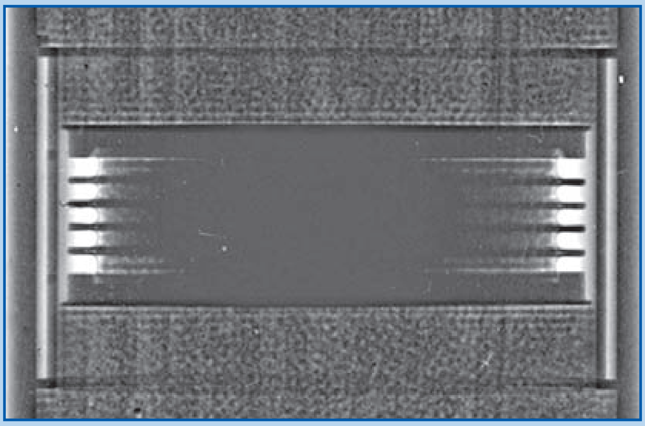


Figure 28 - Neutron radiography of one of the four test elements of the Pebble-Bed Assembly irradiation (a subsized section of the Helium Cooled Pebble-Bed blanket concept)

SPICE (Fusion)

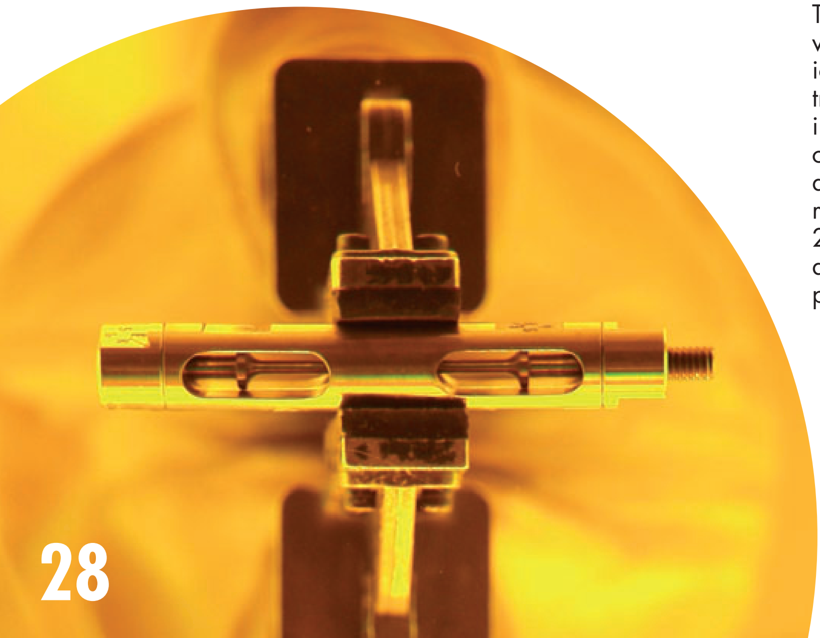
Objectives

The irradiation project SPICE was carried out in the frame of the European Long-Term Fusion Materials Development Programme with the objective to evaluate the mechanical properties of Eurofer 97 samples after irradiation at doses of 15 dpa and at different irradiation temperatures (250/300/350/400/450°C). The material samples were provided by Forschungszentrum Karlsruhe (FZK), Germany and comprised 180 mini charpy, 91 tensile and 160 fatigue specimens.

Achievements 2004

The irradiation was conducted from July 2001 through May 2004. After the rig had cooled down, the specimens were unloaded and prepared for transport back to FZK where they arrived in December 2004 for post-irradiation characterization. Discussions have already begun with FZK to pursue this activity with further specimens.

Figure 26 - Bolt and nut assembly developed for measurements of in-pile stress relaxation behaviour of ITER bolt materials



Helium cooled pebble bed sub-module operation

The nuclear reaction producing power in first generation fusion plants occurs between hot deuterium and tritium at sufficiently high pressure. Since free tritium is insufficiently available in nature, blankets near the fusion plasma are the source for half of the fuel (namely tritium). This fuel is produced by transmutation of lithium through neutrons generated in the plasma.

Present designs look at various forms of lithium in the blankets, such as liquid (e.g. lithium lead) or solid (e.g. pebbles of lithium ceramics). The primary cooling of the blankets is envisaged through pressurised helium. Besides the lithium for the fuel, beryllium has to be mixed somehow with the pebbles to act as a neutron multiplier. Tritium purge lines provide the connection to the tritium storage devices. Arranging lithium bearing compounds, beryllium multipliers, tritium purge lines and cooling devices is quite complex, thereby justifying the experimental demonstration of the basic design parameters.

ITER will serve as a test bed for Test Blanket Modules (TBM), which will provide input for the design of blankets for the Demonstration fusion reactor (DEMO) and for later fusion power plants. Such a TBM also closely needs to follow the design of blankets for DEMO and fusion power plants. It is essential to test ITER blanket sub-modules in materials test reactors. The neutron spectrum in the HFR forms a realistic environment for the testing of blanket modules. Four helium-cooled pebble bed assemblies with lithium-silicates and lithium-titanates, closely following the major design for ITER's intended TBM, were tested during 2003 and 2004 in the HFR.

This irradiation campaign provides experimental data to verify and validate models used for predicting TBM behaviour. On-line process readings of temperatures, pressures and tritium production allowed detailed validation. Tests prior to irradiation contributed to understanding the thermo-mechanical behaviour of pebble bed assemblies. The experiment has already resulted in improvement of the nuclear and thermo-mechanical analyses. Continuation of the experiment into 2004 will help to improve the predictions of TBM behaviour and in particular, regarding beryllium creep. The detailed post-irradiation examinations will be started in 2005.

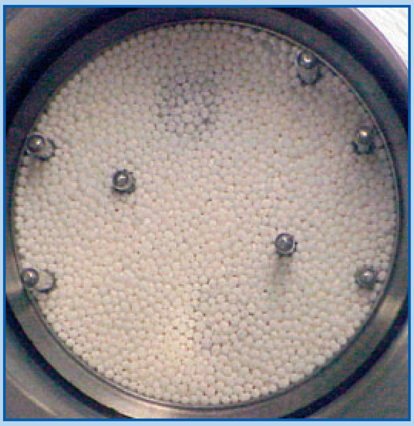


Figure 29 - Loading of the ceramic breeder section of one of the four test elements of the Pebble-Bed Assembly irradiation (a subsized section of the Helium Cooled Pebble-Bed blanket concept)

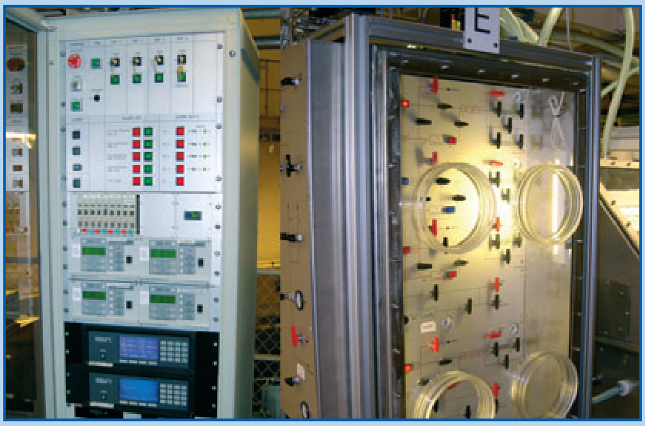


Figure 31 - Instrumentation cabinets and control panels of the extension of the Tritium Measuring Station at HFR, applied for irradiation experiments with tritiated purge lines

Functional fusion blanket materials

In the frame of the EXOTIC (EXtraction Of Tritium In Ceramics) series, the work on post-irradiation ceramography and tritium annealing tests has continued, improving the database for designers, scientists and materials engineers. The information concerns the ceramic tritium sources of primary interest for fusion power development, namely lithium silicates and titanates. The EXOTIC-9 irradiation, currently in the preparation stage, will include the in-pile determination of characteristics of its tritium release, for a special batch of meta-titanate pebbles obtained from CEA (France). A limited size batch with 30% enriched lithium will be tested alongside the major test objects.

Preparation of the HICU experiment (High-fluence Irradiation of breeder Ceramics), aimed at long-term (up to two years) irradiation of ceramic pebbles, is still underway. Conflicting requirements and design complexity have generated difficulties to consolidate a finalised design. In particular, cadmium shielding (required for neutron spectrum adjustment) is hard to combine with high power densities produced by the enriched-lithium ceramics (n,α) and gamma fields; thermo-mechanical behaviour of ceramic pebble stacks generates another design uncertainty. Pre-testing and X-Ray tomography of pebble stacks before irradiation is applied to improve the quality of the results expected from post-irradiation testing. The test matrix and sample selection were slightly modified to accommodate for advanced pebble fabrications. FZK (Germany) and CEA (France) provided additional specimens.

In the frame of the IEA (International Energy Agency) implementing agreement on Radiation Damage Effects in Fusion Materials, beryllium pebble stacks will also be irradiated in the HFR for a four-year period. Partners in the EU, Japan and the Russian Federation provided different grades of beryllium pebbles to be tested in HFR's HIDOBE (High Dose Beryllium Irradiation) rig. The irradiation will be performed in order to quantify their long-term behaviour in terms of swelling, creep and tritium retention and validate their model descriptions. Most of the pre-tests have been completed satisfactorily; the rig manufacturing started in 2004.

Coatings for corrosion prevention and as barrier

Several design approaches use coatings on the structural materials or the piping of fusion blanket components. Coatings have several functions:

- Prevention or reduction of coolant attack on the structural material
- Electrical insulation of the metallic component from the metallic coolant
- Barrier to tritium transport.

The qualification of the double walled tubes with a copper barrier includes the measurement of the crack propagation in the copper layer. A method by potential difference, used for reference testing, turns out to be feasible for post-irradiation testing of multi-layered sandwich assemblies. The solution proposed for testing the crack propagation in hot-cells will be based on the measurement of sample stiffness under a four-point bending test. In addition it is proposed to perform impact tests on sandwiched material in order to obtain information on the copper layer integrity under high velocity loading.

Further irradiation experiments with alternative types of coatings are hampered by the lack of supply of stable coatings. Alternatively the neutron irradiation of pre-oxidised Eurofer97 was considered. Finally it was decided to proceed with an in-situ oxidation process, as it would enable a more direct determination of the integrity and permeation properties of the steel's oxide layer.

Figure 30 - In-pile section with four test elements of the Pebble-Bed Assembly irradiation (a subsized section of the Helium Cooled Pebble-Bed blanket concept)

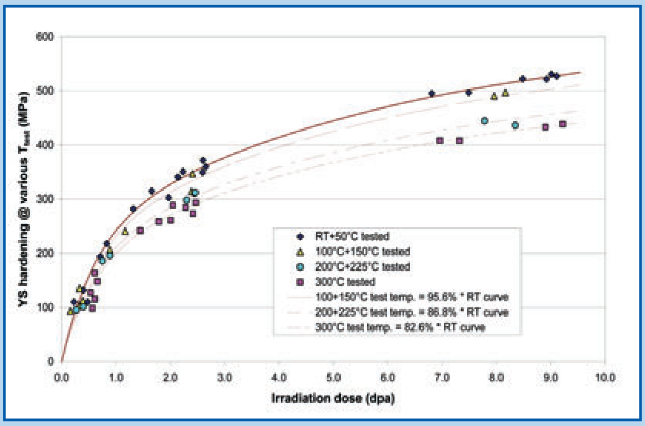


Figure 33 - hardening trends vs. 300°C irradiation dose for Eurofer97 products at various test temperatures

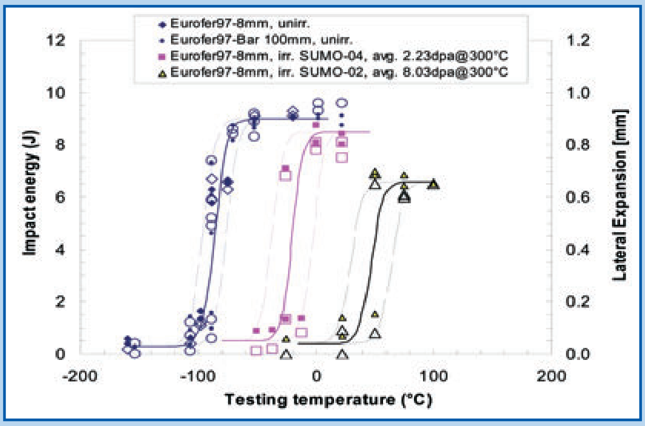


Figure 34 - Impact test results for Eurofer97 products at various doses and test temperatures

Structural steel for ITER test blankets

Austenitic stainless steel is widely used in fission reactor components. The environmental conditions of fusion applications make such steels less attractive because of high swelling rates and helium embrittlement properties[1]. Conversely, with a micro-structural behaviour preventing high swelling rates or helium embrittlement, ferritic martensitic steels have become the reference structural steel for blankets. Another advantage of such steels is that, providing the impurity level can be controlled, they can be made with alloying elements that allow re-processing after less than 100 years. Manufacture of such alloys has been successfully demonstrated by the Japanese and EU steel industry. This class of steels is called Reduced Activation Ferritic Martensitic (RAFM) steel.

A whole set of irradiation projects with post-irradiation testing is necessary to qualify this steel for application in blankets. The first target is the justification for its use in the ITER test blanket modules. In the HFR, a large programme is underway to contribute to the quantification of neutron irradiation effects up to 12 dpa, on RAFM steels.

The irradiation series has been extremely successful in reaching the targets set for the irradiation conditions, especially with respect to temperature. The irradiations are monitored and controlled with regard to temperature. Typically, a SUMO irradiation experiment has 20 thermocouples mounted either in the loading-pin holes and notches of CT specimens or on the surface of tensile specimens. The entire history of the heat profile over any sample holder is thus known with good certainty. The non-instrumented specimen's temperatures are inferred from the ~20 calibration points available. The actual neutron spectra in the HFR irradiation positions is well known and the post-irradiation measurements on the activation sets are used to calibrate and scale the flux profile. Where numerous irradiation data in literature show irregular, non-monotonic hardening with increasing dose, the hardening trend curves for the irradiations mentioned above are smooth and continuous.

The hardening trends for the Eurofer97 products are shown on a linear dose scale at different testing temperatures. It is evident that the trends at higher testing temperature are a simple fraction of the hardening at room temperature. Therefore, the hardening as measured at higher testing temperatures can be divided by this fraction to obtain the hardening if the test had been performed at room temperature.

The impact properties as measured on KLST size samples have shown that Eurofer97 25mm plate has a higher transition temperature in the unirradiated state than the other product forms, which all behave very similarly. After irradiation, the 25 mm plate shows a larger shift of the transition temperature.

In 2004, the testing of irradiated RAFM steel samples has started with a view to quantify irradiation effects on fatigue endurance of blanket modules in ITER. The modules are subjected to fatigue from the intermittent operation of the ITER plasma.

The good experience with the series of SUMO rigs formed the basis for the design of a new multi-temperature irradiation on miniature fracture specimens that is prepared for irradiation in 2005. The fracture behaviour of unirradiated, 250°C, 300°C and 350°C irradiated Eurofer97 14 mm plate in notched bending bars and miniature compact tension specimens will be compared. Specimen miniaturizing is not only driven by rationalisation of the performance/cost ratio of irradiation testing, but furthermore by validation of the testing concepts for the International Fusion Materials Irradiation Facility (IFMIF), currently under design by an international team.

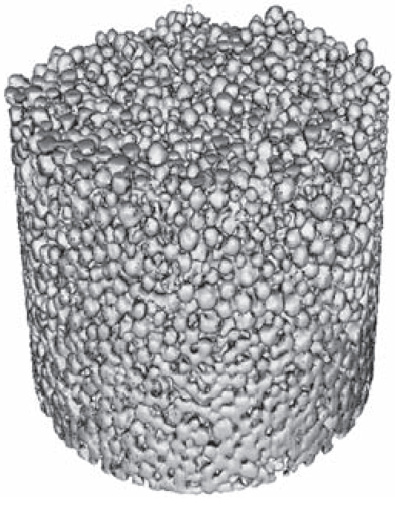


Figure 32 - X-ray tomography for pebble-stack, prototypical for HICU irradiation

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(1) High swelling rates are a consequence of displacement damage due to high energy neutrons, combined with high operating temperatures; helium embrittlement is due to bubbles by helium, resulting from transmutation reactions.

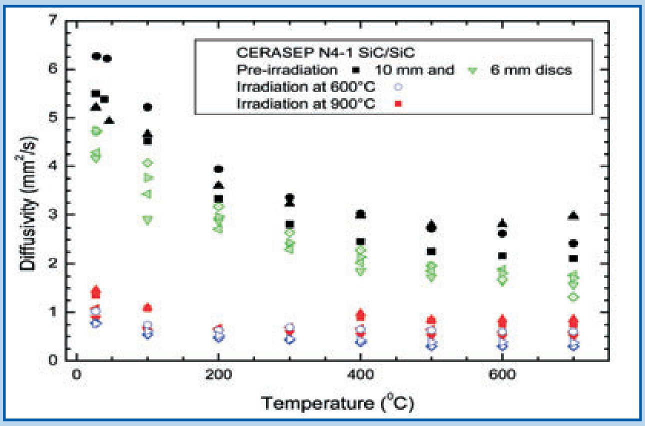


Figure 36 - Thermal diffusivity of a SiCSiC composite before and after irradiation

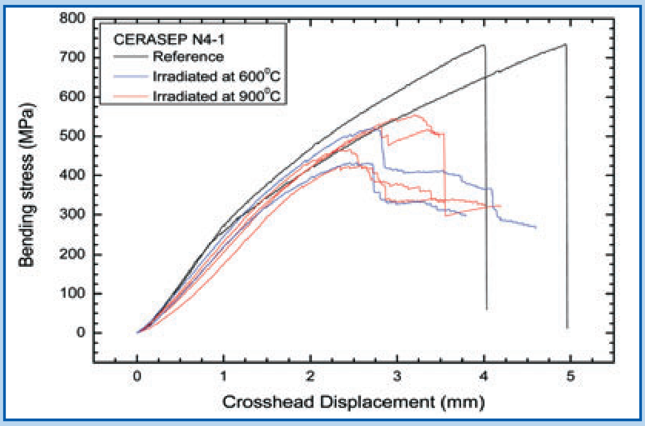


Figure 37 - Deformation curve of a SiCSiC composite before and after irradiation

Silicon carbide ceramic structural material

Providing that the oxide dispersion strengthening of next generation steels is effective, blankets based on steels will allow operational temperatures up to 650°C; another 100°C can be further gained through the use of nano-microstructure stabilisation. However, given that the upper operating temperature of steel will be reached at around 750°C and that higher thermal efficiency can be obtained at operating temperatures over 1000°C, interest is growing in structural materials allowing such operating temperatures. Silicon carbide ceramic composite is a candidate material, which have attractive strength properties up to 1000°C, but also display some drawbacks that need to be eliminated:

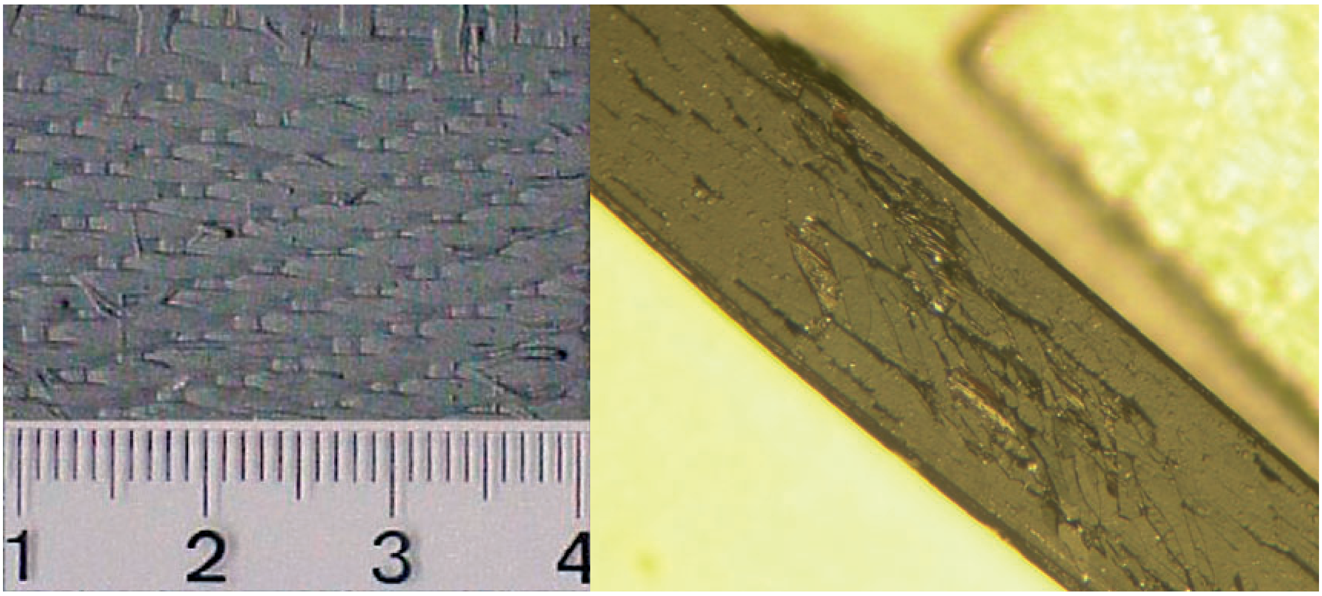
- low heat conductivity after neutron irradiation
- strength reduction by neutron irradiation
- low toughness
- limited leak tightness.

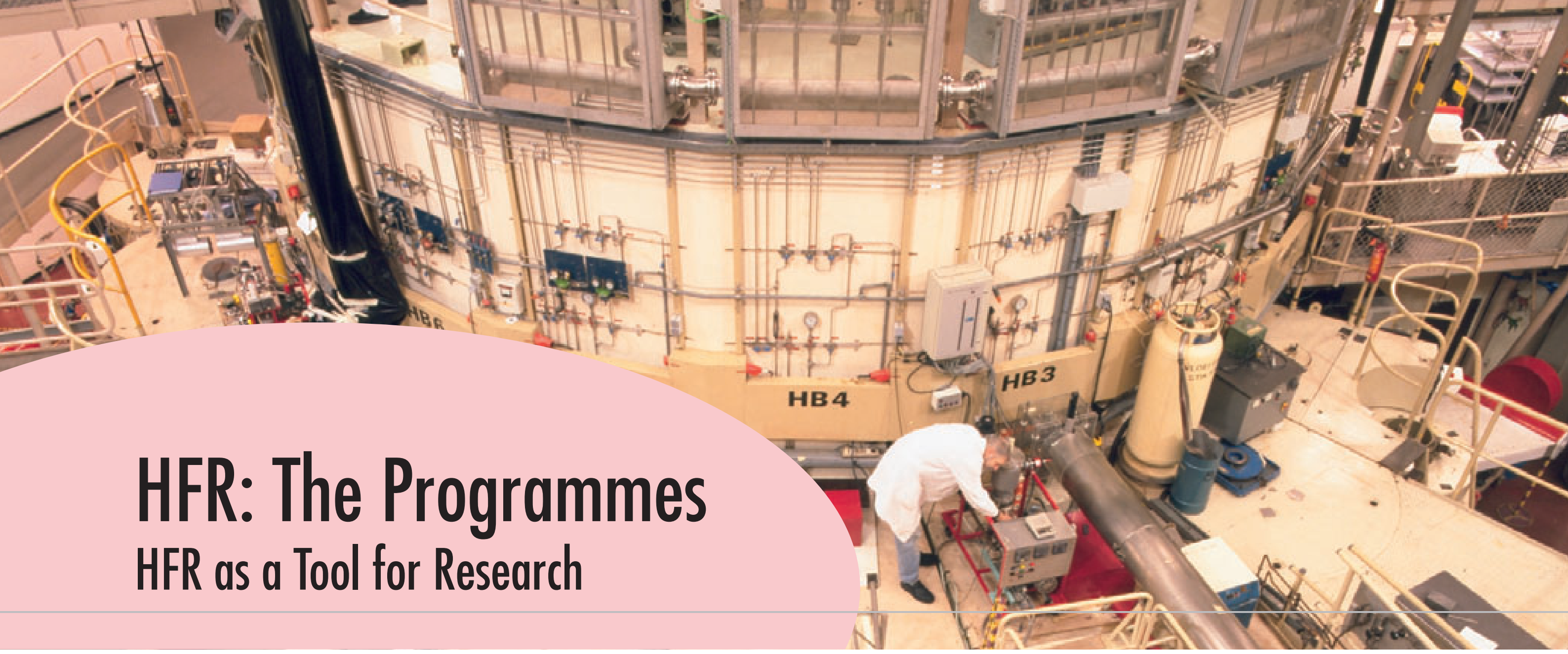
The SICCROWD irradiation at 600°C up to 950°C and Post–Irradiation Examinations (PIE) aim at addressing the major issues related to neutron irradiation. Materials from suppliers in the EU, Japan and the US were irradiated in the rig up to 4.4 dpa in SiC (equivalent to 2.3 dpa in steel). The PIE was completed in 2004. The main results are that:

- dimensional changes are small; < 1% on length at both irradiation temperatures,
- the static and resonance elastic modulus changed from +10% to –25%,
- thermal diffusivity decreased with 50% to 90% at $T_{irr} = T_{meas} = 600°C$; the thermal diffusivity decreased with 25% to 75% at $T_{irr} = 850\text{-}900°C$ and $T_{meas} = 600°C$. This fractional reduction is larger for the better conducting materials,
- the load to fracture in 4-point bending reduced by about a factor of two.

The test methodology forms the basis for a follow-up project with new 2-D and 3-D composites. A hybrid blanket design using steel girders with large parts made from silicon carbide may be the nearest application of such material in fusion power development.

Figure 35 - SiCSiC composite - surface appearance (left) and bend bar side view after irradiation (right)





HFR: The Programmes

HFR as a Tool for Research

Neutron beam research

In 2004 significant efforts were undertaken by JRC to upgrade and revitalize several HFR neutron beam facilities and a large number of neutron diffraction testing campaigns were executed aiming at supporting structural integrity assessment investigations of RPV and Primary Piping welded components.

Several major testing campaigns were executed throughout 2004 based on the HFR Large Component Neutron Diffraction Facility and the Combined Powder and Stress Diffractometer:

- Unidirectional strain measurements on a reactor pressure vessel wall mock-up containing a proposed sub-clad crack repair weld; results to be used for calibration of numerical models (ENPOWER)
- Residual stress measurements in various short C/C-SiC tubular specimens at high temperature were completed (HITHEX)
- Measurements of stress relaxation by heat treatments of multi-pass weld steel specimens in the context of a NET-TG2 round robin; experimental data are also being used for calibration of numerical models under development
- Additional measurement campaign in the context of NET TG1 (single bead on plate); results confirmed findings from earlier test campaigns
- 3-dimensional analysis of residual stresses in an austenitic piping girth weld in the context of a third party contract

New facility for residual stress analyses at HFR/HB5 under development: VISA – the Versatile Instrument for Stress Analysis

Based on technical specifications drafted in 2004 two contracts have been awarded for the development of this new facility. The main features of the new instrument will be:

- A "Tanzboden" type floor, where movements of heavy pieces of equipment can be executed virtually friction free on air pads
- Capacity for handling large specimens of up to 200 kg
- Significantly increased movement ranges of sample table, facilitating investigations in large size stress fields

Upgrading of the HFR/SANS Facility and its Relocation outside the Reactor Containment Building Downstream HFR/HB10

Background

Small-Angle Neutron Scattering (SANS) is a technique used for characterizing sizes (size distributions) and shapes of inhomogeneities in materials and in some cases their mutual interactions. Applications in material science include; phase stability of alloys, interface studies, grain boundaries studies, nucleation and growth of precipitates of alloys, characterization of distributed damage in metals and ceramics subjected to creep, fatigue, microstructural changes after heat treatment, porosity of materials, nanocrystalline materials and influence of grain size, non-magnetic materials, in-situ densification of ceramics, segregation processes, and voids & defects. SANS is currently emerging as a powerful non-destructive method for the investigation of irradiation and thermal ageing induced damage in steel alloy weld materials.

Characteristics of current HFR/SANS & comparison with similar European Facilities

The HFR Small Angle Neutron Scattering (SANS) facility has been developed and built in the late 80's - early 90's in the context of the then ECN research activities on solid state physics. At present, re-commissioning of the SANS facility is underway to facilitate analysis of damage occurring in metallic material specimens as a consequence of thermal ageing, welding or irradiation.
HFR/SANS, designed 20 years ago, is in many aspects similar to many state of the art SANS facilities in Europe. However, wavelength selection at the HFR/SANS is achieved by means of a double monochromator, which facilitates diversion of the employed neutron beam to the upper level of the reactor hall due to space requirements for its neutron detector vacuum chamber. This however results in significant reduction of its neutron flux and lack of access to the desired wavelength range. Furthermore, HFR/SANS is not equipped with a cold neutron moderator, which could shift the neutron spectrum toward the desired longer wavelengths. These two drawbacks of the existing facility are the main reason why HFR/SANS is currently operating with a significantly lower neutron flux compared to other neutron sources in Europe.

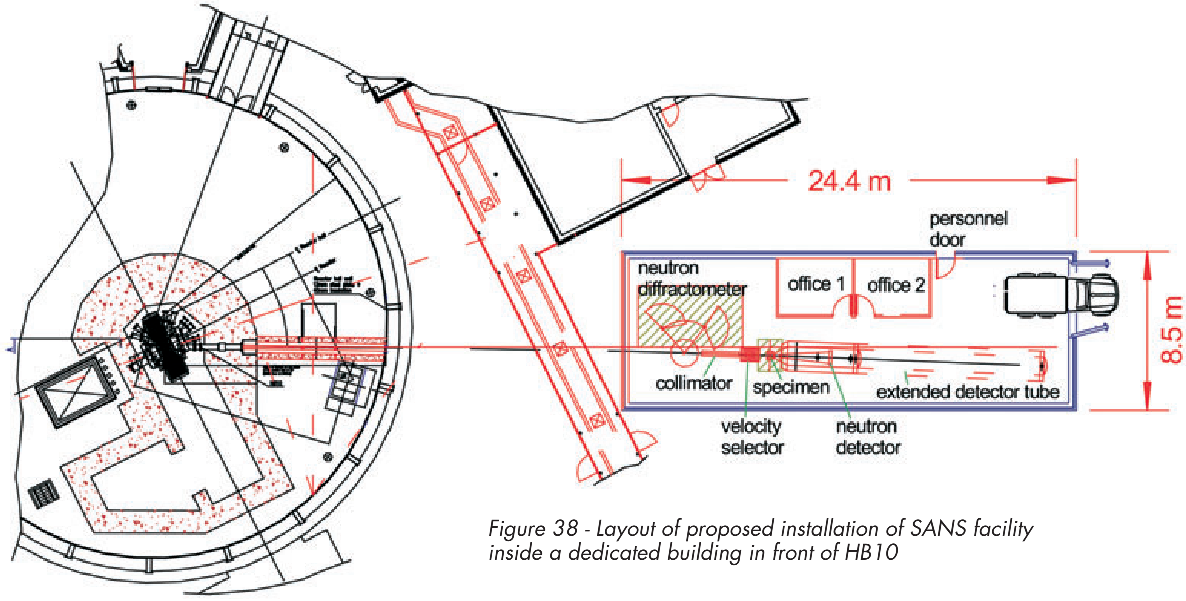


Figure 38 - Layout of proposed installation of SANS facility inside a dedicated building in front of HB10

The HFR/SANS facility has main characteristics comparable to those of other European SANS instruments with pinhole geometry. Concerning the scattering vector Q, most facilities operate in the range 10^{-3} to 0.4 $Å^{-1}$. The HFR/SANS facility has a range of accessible Q values between 5×10^{-3} and 0.4 $Å^{-1}$, and this range covers well the values 10^{-2} – 0.4 Å-1 usually needed for investigation of irradiation defects. The accessible size range for the HFR SANS facility is roughly 1-100 nm.

However, the neutron flux at HFR/SANS is ca. 10^4 n $cm^{-2}s^{-1}$, and based on the proposed upgrade it is expected to be in the range of 10^6 n $cm^{-2}s^{-1}$ as is available at most state-of-the-art facilities in Europe. In addition, the envisaged upgrade will give access to the desired range of longer wavelengths, i.e., 5 to 20 Å.

This upgrade of the SANS facility performance should allow for the investigation of defects in a large class of cases, including irradiated material specimens. This capability, coupled with the HFR irradiation facilities and the new LCNDF version for neutron diffraction on irradiated specimens will result in a unique and autonomous Combined HFR Laboratory for RPV welded internals characterization within Europe.

Objectives/Applications

The main objective of the new HFR/SANS facility is to develop the capability to efficiently analyze radiation, thermal ageing and fatigue induced damage in welded steel alloy materials in the context of the SAFELIFE Action and the NET European Network.

In addition, it is expected to contribute to investigations in the context of future institutional and competitive activities in areas, such as,
- Innovative reactor concepts
- Fusion technology
- Characterization of spent fuel

It should be stressed that damage and microstructure investigations based on SANS facilities are emerging as a formidable source of competitive income, more so than residual stress analysis based on neutron diffraction.

Evolution of upgrading concept

The purpose of the proposed facility upgrade is to increase the current SANS neutron beam intensity by ca. two orders of magnitude and to give access to the desired wavelength range (5 –20 Å) for defects analysis.

Based on initial feasibility studies, carried out in the course of 2004, the installation of a sophisticated cold neutron source based on Mesitylene as moderating material was examined. However this option was rejected in September 2004, on the basis of questionable performance of such a moderating material particularly in a HFR environment and a simpler and safer option was adopted. It should be noted that another option of sophisticated cold neutron source, based on hydrogen, was also rejected based on its higher cost on specific “HFR safety culture norms”. In early Autumn 2004, an internal campaign was initiated to obtain the consent of the HFR Safety Committee and the Reactor Safety Committee to the concept of introducing the most appropriate HFR horizontal neutron beam, i.e. HB10, and the SANS facility outside of the HFR containment building. The consent of both committees was obtained in early 2005.

Proposed main modifications

The current SANS facility on the first floor of the HFR Hall will be removed to the ground level, directly downstream of the HB10 beam and outside the reactor containment building, using a slightly curved neutron beam guide of high efficiency, in order to remove undesirable fast neutrons and gamma radiation at the sample location, without significant reduction in neutron flux at the desired wave length.

A dedicated building will be constructed near to the HFR to house the SANS facility (see Figure 38) in accordance with state of the art safety standards. Provision will be made to the building, such that, if necessary, another neutron diffractometer could be located in the future.

A neutron cold source and reflector based on beryllium at the entrance of the HB10 beam will be developed and installed. A cold beryllium block will be placed inside HB10 and very near to the core. The temperature of the beryllium should be kept within 80-100 K. This will enable cold neutrons with wavelengths longer than the beryllium cut-off to penetrate through the block free of collision.

A neutron velocity selector will be installed, which will replace the currently installed double-monochromator and will give access to high neutron wavelengths (5 – 20 Å).

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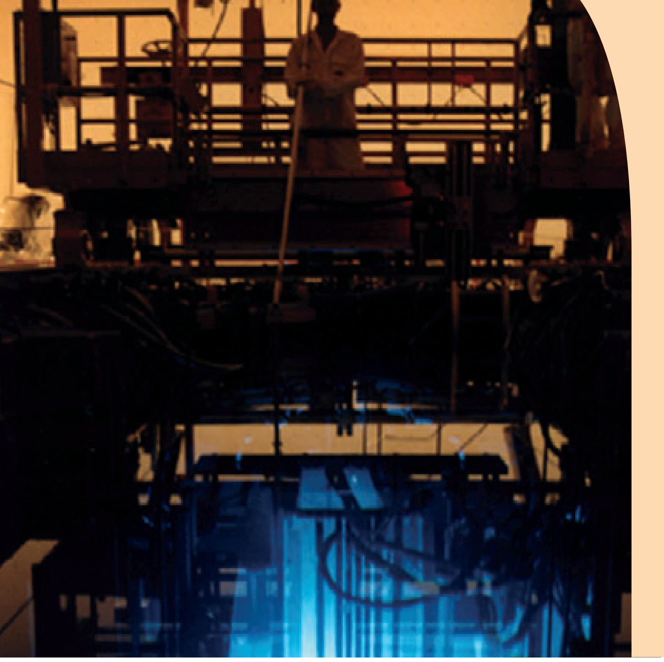
A list of HFR scientific publications mentioned in this Annual Report can be obtained upon request to the contact person.

Glossary

ADS	Accelerator Driven Systems
AHG	Ad-Hoc-Group
AMES	Ageing Materials Evaluation Studies
BNCT	Boron Neutron Capture Therapy
BoT	Board of Trustees
BPA	Boron compound for BNCT
BSH	Boron compound for BNCT
BT	Brain Therapy
BWR	Boiling Water Reactor
CASHIR	Cadmium-Shielded Steel Irradiation Experiment
CEA	Commissariat à l'Energie Atomique
CEN	The European Committee for Standardization
CHIP	Chilean Irradiation Project
CMC	Ceramic Matrix Composite
COVRA	Centrale Organisatie Voor Radioactief Afval
DEMO	Demonstration Fusion Reactor
DG	Directorate General
DMW	Dissimilar Metal Welds
dpa	displacements per atom
EANM	European Association of Nuclear Medicine
EC	European Commission
ECN	Energieonderzoek Centrum Nederland
EdF	Electricité de France
EFDA	European Fusion Development Agreement
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
ENPOWER	Nuclear Plant Operation by Optimising Weld Repars
ENSAM	Ecole Nationale Supérieure d'Arts et Metiers
EORTC	European Organisation for Research and Treatment of Cancer
ESTRO	European Society for Therapeutic Radiology and Oncology
EU	European Union
EUROTRANS	European Transmutation
EXOTIC	EXtraction Of Tritium In Ceramics
EXTREMAT	New Materials for Extreme Environments
FIMA	Fissionable (Heavy) Metal Atoms
FLUX	Fluence Rate
FP or FWP	Framework programme
FRAME	Fracture Mechanics Based Embrittlement Trend Curves for the Characterisation of Nuclear Pressure Vessel Materials
FUJI	Fuel Irradiations for JNC and PSI
FZK	ForschungsZentrum Karlsruhe
GIF	Generation IV International Forum
HABOG	Hoogradioactief Afval Behandelings- en Opslag Gebouw
HAZ	Heat Affected Zones
HB	HFR Beam Tube
HELIOS	Helium in Oxide Structure
HEU	High Enriched Uranium
HFR	High Flux Reactor
HICU	High-fluence Irradiation of breeder Ceramics
HIDOBE	High Dose Beryllium Irradiation Rig
HIPOS	High Intensity Positron beam
HITHEX	High Temperature Heat Exchanger
HT	High Temperature
HTR	High Temperature Reactor
IEA	International Energy Agency
IAEA	International Atomic Energy Agency
IASCC	Irradiation Assisted Stress Corrosion Cracking
ICI	International Conference on Isotopes
IE	JRC Institute for Energy, Petten (NL)
IFMIF	International Fusion Materials Irradiation Facility
IIS	International Isotopes Society
IMRT	Intensity Modulated Radiotherapy
INET	Institute of Nuclear Energy Technology (of the Tsinghua University)
INNOGRAPH	Innovative Graphites
INSARR	Integrated Safety Assessment of Research Reactors
INTERWELD	Irradiation effects on the evolution of the microstructure, properties and residual stresses in the heat affected zone of stainless steel welds
IP	Integrated Project
IRI-Delft	Interfaculty Reactor Institute, Delft (NL) University of Technology



ISO	International Organization for Standardization
ITER	International Thermonuclear Experimental Reactor
ITU	Institute for TransUranium Elements, Karlsruhe
JET	Joint European Torus
JRC	Joint Research Centre
KLST	specimen for impact testing according to the German standard DIN 50115
LCNDF	Large Component Neutron Diffraction Facility
LEU	Low Enriched Uranium
LWR	Light Water Reactor
LYRA	Irradiation Facility for European Network for AMES
MCNP	Monte Carlo Neutron Photon
MICROMOX	Mixed Oxide (MOX) Fuel with Improved Microstructure
MIT	Massachusetts Institute of Technology
MOX	Mixed Oxide
MTR	Material Testing Reactor
MYKONOS	Molybdenum Production for Mallinckrodt Diagnostica
NCT	Neutron Capture Therapy
NCPPlan	Neutron Capture Therapy Treatment Planning
NESC	Network for Evaluating Structural Components
NET	Network on Neutron Techniques Standadisation for Structural Integrity
NRG	Nuclear Research and consultancy Group
PIE	Post Irradiation Examinations
PISA	Phosphorus Influence on Steel Ageing
PMMA	Polymethyl methacrylate
PROFEET	Prototype LEU Fuel Test
PSF	Pool Side Facility
PWR	Pressurized Water Reactor
R&D	Research and development
RAFM	Reduces Activation Ferritic Martensitic (steel)
RI	Radioisotopes
RPV	Reactor Pressure Vessel
SAFELIFE	Safety of Aging Components in Nuclear Power Plants
SANS	Small Angle Neutron Scattering
SCWG	Safety Culture Working Group
SCWR	Super Critical Water cooled Reactor
SICCROWD	SIC-SiC composites, Chromium and tungsten (W) irradiation
SPICE	Sample Holder for Irradiation of Miniaturized Steel Specimens
SPIRE	Spallation and Irradiation Effects
STROBO	Stress Relaxation of Bolt Materials
SUMO	In-Sodium Steel Mixed Specimens Irradiation
TBM	Test Blanket Modules
TC	Technical Committee
TG	Task Group
TIRO	Thermal Flux Irradiation Device for Radioisotopes Production
TN	Technology Network
TRABANT	Transmutation and Burning of Actinides in a TRIOX
TRIO	Irradiation device with three thimbles
TRIOX	TRIO modified for irradiation of MOX fuels
TU	Technische Universiteit
US	United States
VHTR	Very High Temperature Reactor
VU Amsterdam	Vrije Universiteit Amsterdam
VVER	Russian Pressurized Water Reactor
WWER	Water Water Energy Reactor

European Commission

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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 the commercial activities.

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

2004 was the first year of the 2004-2006 Supplementary Programme adopted by the European Council on 19th February 2004. 2004 was also the year of the public debate on the new HFR licence requested at the end of 2003. Other 2004 highlights include:
- *286 operational days*
- *220 visits, including representatives from the neighbouring municipalities*
- *4 European Networks managed*
- *Various fusion and fission related irradiation experiments carried out*

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