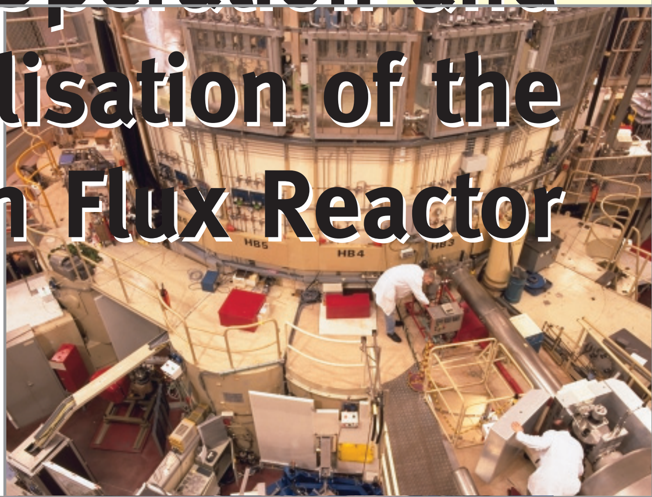
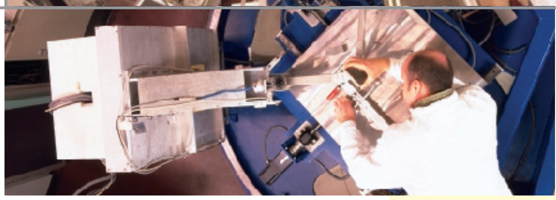
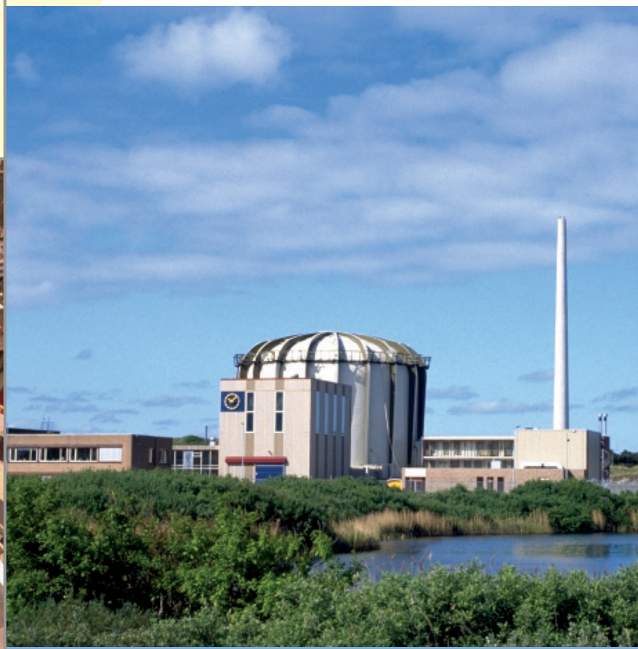
# Operation and Utilisation of the High Flux Reactor







Annual Report 2001

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Institute for Energy

EUR 20530 EN

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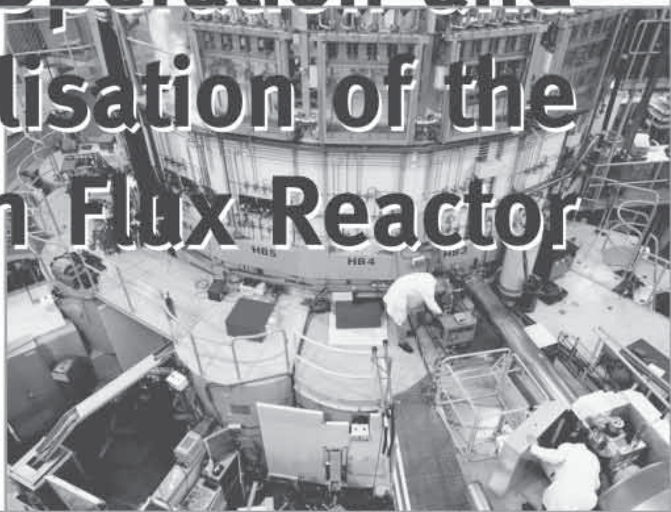

## Annual Report 2001

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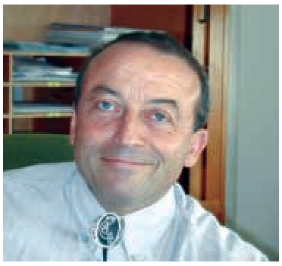
HFR IN THE ENERGY VALLEY AT THE PETTEN SITE.
A CENTRE OF EXCELLENCE FOR NUCLEAR APPLICATIONS FOR MEDICINE IN EUROPE.

# Foreword

**HFR - still producing the same neutron fluences and quality after forty years, but their use for the European citizen is changing constantly and adapting year after year to their needs**



J. Guidez
HFR Unit Head

The year 2001 was for the High Flux Reactor the 40th anniversary since its first criticality in November 1961. The celebration organised on the Petten site on this auspicious occasion allowed all the prominent actors and customers to come together to make an historical overview of the past decades of HFR useage, but also to give some perspective on the future of the HFR programmes.

From 1961 to 2001, the reactor has always operated at the highest level of safety and with the highest number of operating days per year in Europe. It is true that the neutrons produced in 2001 are the same quality and nature as those in 1961, but what an evolution in their utilisation!

In the medical field, almost none of the radioisotopes produced currently and used each year by several millions of European patients, were produced in the 1960's. The use of technetium became extremely important in the 1980's, and its need has increased year after year. Samarium was introduced in the 1990's to treat pain relief (palliation) in bone cancer. In the annual report of last year, we introduced a new product for prostate cancer treatment.

Now nuclear medicine is in constant progress, adaptation and evolution. For BNCT, following years of preliminary research, the first patient in Europe to be treated by BNCT was irradiated at the HFR in October 1997. Similar facilities, with clinical trials in progress, can now be seen at a dedicated reactor in Finland (since 1999), at the Rez reactor in the Czech Republic (since 2000) and at the Studsvik reactor in Sweden (since 2001).

In nuclear research, new materials and new fuel, which are being tested today in the HFR, did not exist several years ago. This continuous scientific progress is possible due to the policy for continuous testing of new and improved products. This is a major contribution to maintain European competence and advantages in this field. In the generation 4 process, engaged by the US authorities to develop new reactors for the future, the HFR with its related networks (AMES, HTR-TN, EFTTRA, and others), is an important tool in maintaining in Europe the scientific leadership in this field.

The horizontal beam tubes are regularly upgraded for new utilisation, such as beam tubes HB11 and HB12, which were changed in 1984 in anticipation of new medical applications. More recently, beam tube HB4 was upgraded in 1998 to permit residual stress measurements to be performed more efficiently and accurately. The industrial needs in this field continue to increase, whilst the first measurement techniques were validated in the 1990's.

In conclusion, neutrons are the same in number and quality since 1961, but during the last 40 years research and utilisation programmes of the HFR have changed continuously to follow the needs of the European citizen. A good example of this adaptation will be the next 6th Framework Programme, where many new programmes are already in discussion in the frame of the European Research Area activities.

J. Guidez

# Introduction

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

The HFR is of the tank-in-pool type, light water cooled and moderated and operated at 45 MW. In operation since 1961, and following new vessel installation in 1984, the HFR has a technical life beyond the year 2015.
The reactor provides a variety of irradiation facilities and possibilities, [1], [2]: in the reactor core, in the reflector region, in the poolside. Horizontal beam tubes are available for research with neutrons. Gamma irradiation facilities are also available. Excellently equipped hot cell laboratories, on the Petten site, can provide virtually all envisaged post-irradiation examinations.

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

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

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



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

A technical co-operation agreement on safety is under discussion with the two other “sister”-reactors, R2 (Sweden) and SAFARI (South Africa).

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

# Highlights

## 40 YEARS OF HFR

The HFR first went critical on 9th November 1961 and the 40th anniversary of this event was organised in 2001.

## PLANT OPERATION

During 2001, excellent performance results were obtained:
- 291 days of operation, with an in-service inspection in the summer shut down
- Problem-free technical operation of the reactor
- Upgrading of various components

## BUDGET 2000-2003

The budget 2000-2003 was approved by the European Council in December 1999 and is shown in Figure 1. The financial support for this four years programme includes 34 M€ from The Netherlands, 3.8 M€ from Germany and 1.2 M€ from France. The remaining part of the budget (about 45%) has to be found in the competitive market.
The budget includes all foreseen costs, such as, for example, the studies necessary to obtain a new licence, the high radioactive waste, provision of decommissioning, spent fuel storage, etc.

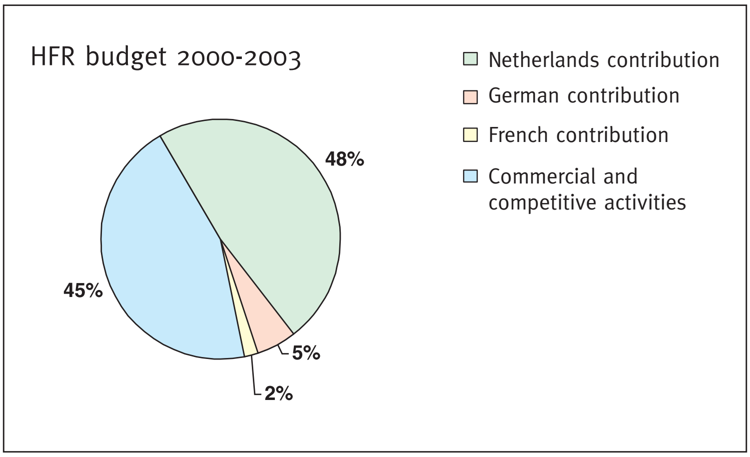



Figure 1: HFR budget for the period 2000-2003

## QUALITY

Both JRC and NRG have management systems certified according to the ISO9001 standards. Successful audits were conduced in 2001, to maintain these certifications.

## HFR CONVERSION TO LOW ENRICHED URANIUM

The decision was taken in 1999 to convert the reactor to Low Enriched Uranium (LEU). Diplomatic notes were signed in January 2000 with US authorities to take this commitment. The conversion studies phase 1 and phase 2 were achieved and a prototype LEU fuel element has been ordered in 2001 [6]&[7].

## FUEL CYCLE

A shipment of spent fuel to the US was made. HEU fuel supply was provided from the US.

## HFR UTILISATION IN 2001

The average value of HFR utilisation was about 73% of the maximum technical possibilities.
In the medical field, the HFR, the European leader for radioisotope production, continues to assure the production necessary for treatment and diagnosis of several millions of European citizens each year. Furthermore, the BNCT project started treatment of a fourth group of patients, to improve research into the treatment against glioblastoma, a cancer that kills each year about 15000 citizens in the EU.
In the nuclear energy field, many experiments on fuel and material irradiations were performed successfully:

- Ageing of materials for nuclear safety (especially for Eastern reactors)
- Testing of materials for new reactor concepts (fusion, HTR, spallation, etc.)
- Testing of fuel for safety improvement or for new reactor concepts
- Transmutation testing for nuclear waste policy.

New measurements were performed on beam tube HB4, updated in 1998, and HB5.

## MEDICAL USE

The HFR continues to be the main European provider for radioisotopes production. Each year, several millions of European citizens are using HFR products.

## NEW EUROPEAN PROJECTS

European networking around the HFR is increasing yearly. For example, the Network created around High Temperature Reactor Technology (HTR-TN) has been a success and has led to new European developments and several new technical projects in the HFR.

## SAFETY

A meeting was organised in South Africa in December 2001, with the two “sister” reactors in operation (built by the same company in the 1960’s): R2 (Sweden) and SAFARI (South Africa). It allowed a full exchange of information in safety matters.

# 1961-2001 HFR: Essential for Energy and Health

HFR, “Essential for Energy and Health” was the title of an international symposium on the occasion of the 40th anniversary of the High Flux Reactor.

The symposium was attended by over 150 delegates from all over Europe. Prominent speakers from the government, nuclear industry and the medical world underlined the importance of the HFR.

## GENESIS

Some 50 years ago, nuclear energy was seen as one of the main forms of energy generation in Europe. In many European countries national authorities considered that it was critical to have the possibility to further develop nuclear knowledge in order to construct, operate and manage nuclear power plants in a secure and reliable manner, At that time, Dutch authorities decided to initiate the Reactor Centre Netherlands (RCN) and to build the High Flux Reactor (HFR), a so-called materials research reactor.

The dunes in Petten were selected as the location for this innovative project. In August 1957, the construction of the HFR started.

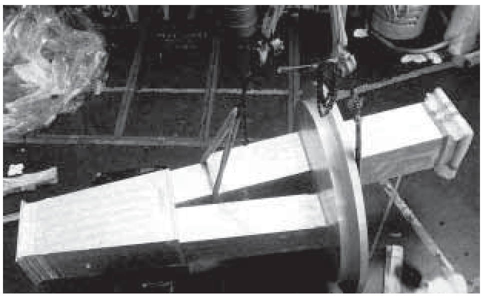
Construction at the Petten site 1957

On the 9th November 1961, the HFR reached its first major milestone, the reactor was started for the first time and during 1962, the reactor came into full operation. This prestigious project was now a reality and would form a focus point for nuclear research in years to come. In order to facilitate European usage of this unique facility, the Dutch authorities decided to transfer the ownership of the HFR to the European Commission in 1962.

Queen Juliana of The Netherlands visited the reactor in 1962

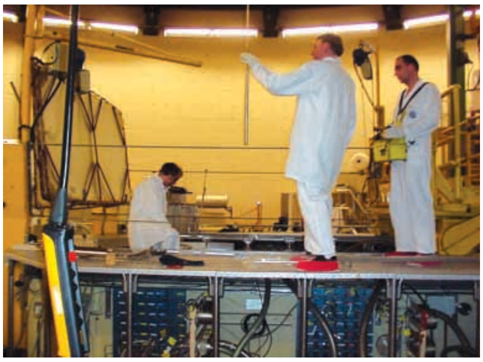
## 1962-1984

From 1962 onwards, the reactor was intensively used by The Netherlands and Germany for various nuclear research projects. In particular, the research focused on safety, beam tubes, ageing of new materials.



New beam tube installation

Technological development did not stand still during these years. Neutrons from the HFR were used in many new applications.



Operators working at the reactor pool

In 1984, the reactor vessel was replaced and new irradiation possibilities became available. This was an important step in facilitating medical research and it resulted in a substantial increase in the production of radio-isotopes.

## 1984-2001

The share of medical applications in the total research programme increased importantly in the period after 1984. In recent years, over 7 million medical treatments (diagnostics and therapy) per year have been made possible using radio-isotopes from Petten. Furthermore, since 1989, a global European consortium has been working on the development of Boron Neutron Capture Therapy (BNCT), a therapy for patients suffering from glio-blastoma, a very aggressive type of brain tumour. By means of infusion of a boron-containing compound, which concentrates in the tumour, the patient is irradiated with neutrons from the HFR, which destroy the tumour whilst sparing the healthy tissue.

Hospitals can no longer imagine working without nuclear medicine. The availability of radio-isotopes is of strategic importance. Every year more patients rely on the radio-isotopes provided by the HFR in Petten. The high reliability and availability of the HFR in combination with an outstanding nuclear infrastructure such as hot cells and waste treatment facilities in Petten are essential for a guaranteed delivery of radio-isotopes to hospitals throughout Europe.

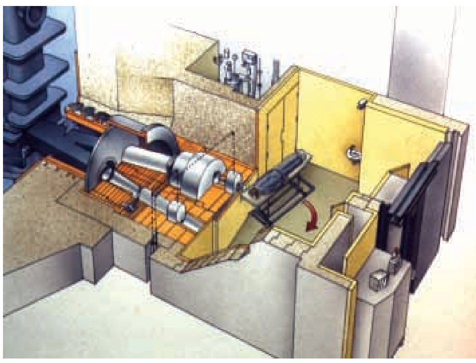
## THE FUTURE

Although it is impossible to predict exactly what will happen in the future, the following activities will undoubtedly play a key role:

Nuclear safety research (especially for EU-applicant countries)

The development of medical applications of nuclear technologies (including the development of new radio-isotopes for medical and industrial purposes)
Research into lifetime reduction of nuclear waste.

However, what is certain is the continuing need for this unique facility as has been demonstrated in the previous years. The demand for knowledge in both the medical and safety domains, and in strategical importance for both radio-isotopes and specific nuclear testing facilities has clearly established the necessity for this unique facility.



The BNCT treatment facility



Forum
Forum







already









# HFR: The Reactor

## HFR OPERATION AND RELATED SERVICES

In 2001 the regular cycle pattern consisted of a scheduled number of 290 operation days and two maintenance periods of 19 and 24 days. In reality the HFR was in operation during 291 days (Figure 3), closely following the scheduled operation programme. This corresponds to an actual availability of 100.7 % with reference to the scheduled operation plan. Nominal power has been 45 MW with a total energy production of approximately 13087 MWd, corresponding to a fuel consumption of about 16.3-kg 235U.

At the beginning of the reporting period, the HFR was in operation for the performance of cycle 00.12. Halfway through the reporting period the measurements for the FLUX 2001 programme have been performed.

Towards the end of this reporting period the yearly HFR reactor-training programme has been carried out.

The operating characteristics for 2001 are given in Table 1.

All details on power interruptions and power disturbance occurred in 2001 are given in Table 2. It appears that 18 scrams occurred. This high value is in fact still due to problems arising last year (2000) following renewal of instrumentation for the PSF cooling water circuits extension. Out of the 18 scrams, 11 are due to this instrumentation. In October, a modification of the instrumentation of the PSF cooling water system decreased the number of scrams at the end of the reporting period.

In 2001 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, which started last year, attracted many visitors. After the occurrence of the 11th September attack, the possibility to visit the HFR has been suspended for the time being. Nevertheless, a total of 1194 people divided over 142 tours were guided through the facility.

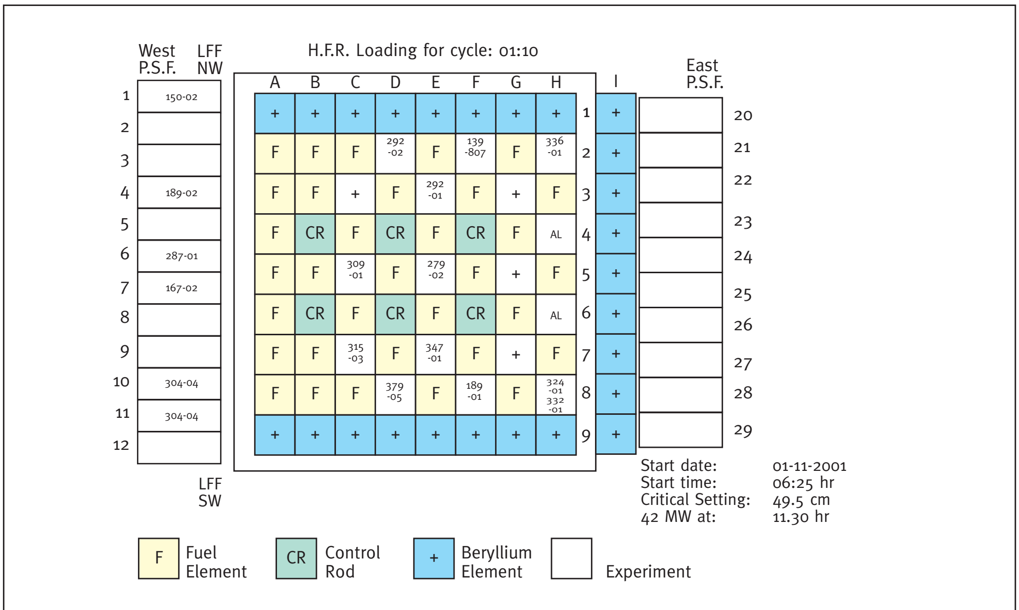



Figure 2: HFR Loading scheme for cycle 01.10

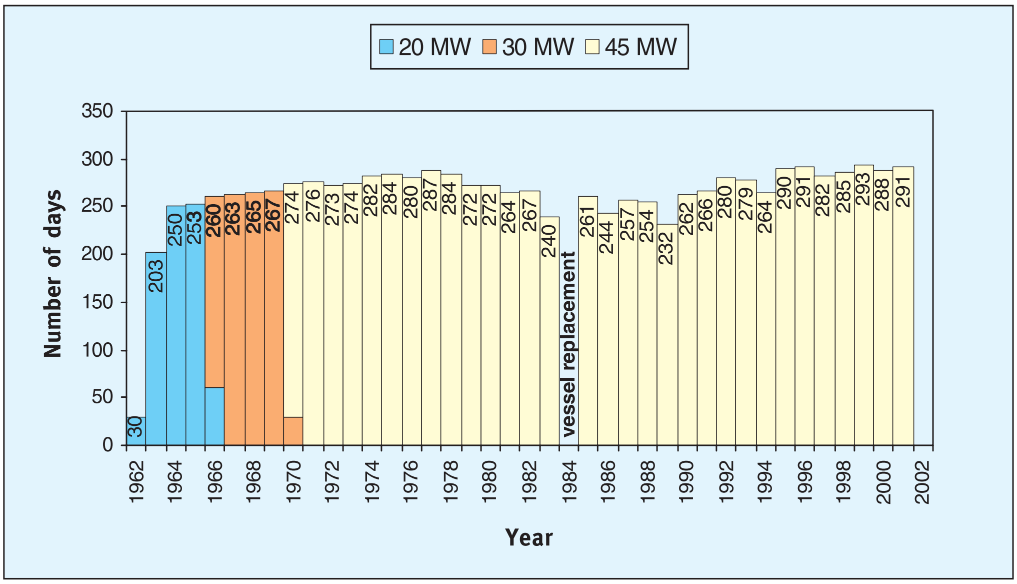



Figure 3: HFR operational record from 1962 to 2001

Table 1: 2001 operational characteristics

| | | | OPERATING TIME | | | | | SHUT-DOWN TIME | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cycle Begin-End | HFR Cycle | Generated Energy | Planned | Low Power | Nominal Power | Other Use | Total | Planned | Un-scheduled | Number of Interruptions | | Stack Release (of Ar-41) |
| 2001 | | MWd | Hrs | h.min | h.min | h.min | h.min | h.min | h.min | PD | Scram | Bq x E+11 |
| | | | | | | | | | | | | |
| 01.01-15.01 | 00.12 | 660.31 | 352 | | 352.00 | | 352.00 | 08.00 | | | | 06.06* |
| 16.01-12.02 | 01.01 | 1140.05 | 592 | 02.14 | 606.56 | | 609.10 | 62.45 | 00.05 | 1 | 1 | 05.61 |
| 13.02-12.03 | 01.02 | 1056.78 | 592 | 02.26 | 562.46 | | 565.12 | 62.06 | 44.42 | | 2 | 10.10 |
| 13.03-30.03 | Maintenance period | | | | | | | 431.00 | | | | |
| 31.03-23.04 | 01.03 | 1045.97 | 544 | 03.18 | 558.06 | | 561.24 | 14.11 | 00.25 | | 2 | 05.52 |
| 24.04-21.05 | 01.04 | 1136.63 | 592 | 01.56 | 605.51 | | 607.47 | 64.00 | 00.13 | | 3 | 06.06 |
| 22.05-18.06 | 01.05 | 1121.24 | 592 | 07.16 | 596.34 | | 603.50 | 63.45 | 04.25 | | 3 | 05.01 |
| 19.06-16.07 | 01.06 | 1138.49 | 592 | 03.04 | 606.08 | | 609.12 | 62.37 | 00.11 | | 2 | 05.71 |
| 17.07-09.08 | Maintenance period | | | | | | | 576.00 | | | | |
| 10.08-03.09 | 01.07 | 1089.56 | 592 | 05.29 | 580.04 | | 585.33 | 08.00 | 06.27 | 2 | 1 | 6.28 |
| 04.09-01.10 | 01.08 | 1131.92 | 592 | 01.38 | 603.33 | | 605.11 | 66.45 | 00.04 | | 1 | 5.33 |
| 02.10-29.10 | 01.09 | 1117.67 | 592 | 03.04 | 595.05 | 02.19 | 600.28 | 72.28 | 00.04 | | 1 | 5.36 |
| 30.10-26.11 | 01.10 | 1135.11 | 592 | 05.39 | 603.42 | | 609.21 | 62.25 | 00.14 | 2 | 2 | 8.86 |
| 27.11-24.12 | 01.11 | 1190.89 | 592 | 04.49 | 629.20 | 18.10 | 652.19 | 61.50 | 05.51 | | | 6.68 |
| 25.12-31.12 | 01.12 | 122.55 | 96 | 02.12 | 64.20 | | 66.32 | 24.00 | 29.28 | | | - |
| | | | | | | | | | | | | |
| TOTAL : | | 13087.17 | 6912 | 43.05 | 6964.25 | 20.29 | 7027.59 | 1639.52 | 92.09 | 5 | 18 | 76.58 |
| Percentage of total time in 2001 (8760 h) : | | | | 0.49 | 79.50 | 0.23 | 80.23 | 18.72 | 1.05 | | | |
| Perc. Of planned operating time (6912 h) : | | | | 0.62 | 100.75 | 0.29 | 101.68 | | | | | |
| PD: Power decrease | | | | | | | | | | | | |

Table 2: 2001 full power interruptions of HFR

| DATE | CYCLE | TIME OF ACTION | RESTART OR POWER INCREASE | NOMINAL/ ORIGINAL POWER | ELAPSED TIME TO | | DISTURBANCE CODE | | | | REACTOR SYSTEM OR EXPERIMENT CODE | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | RESTART OR POWER INCREASE | NOMINAL/ ORIGINAL POWER | 1 | MW | 2 | 3 | | |
| 2001 | | hour | hour | hour | h.min | h.min | | | | | | |
| 23 Jan | 01.01 | 18.54 | 18.59 | 19.10 | 00.05 | 00.16 | AS | 0 | E | H | PSF coolwater | Manual mistake during experiment handling |
| 09 Feb | 01.01 | 23.59 | | | | | AP | 37 | R | H | Power demand | Manual intervention during experiment handling |
| 10 Feb | 01.01 | 00.00 | 00.02 | 00.01 | 00.03 | | | | | | | |
| 21 Feb | 01.02 | 17.35 | 17.41 | 17.53 | 00.06 | 00.18 | AS | 0 | R | E | Mains outage | Due to disturbance of mains supply |
| 07 Mar | 01.02 | 01.37 | | | | | AS | 0 | E | I | 266-02 | Due to disturbance of coolant instrumentation |
| 08 Mar | 01.02 | | 22.20 | 44.36 | 45.43 | | | | | | | |
| 03 Apr | 01.03 | 14.58 | 15.03 | 15.15 | 00.05 | 00.17 | AS | 0 | E | I | 266-03 | Due to disturbance of coolant instrumentation |
| 05 Apr | 01.03 | 09.06 | 09.19 | 09.32 | 00.13 | 00.26 | AS | 0 | E | I | 266-02/06 | Due to disturbance of coolant instrumentation |
| 28 Apr | 01.04 | 02.36 | 02.41 | 02.55 | 00.05 | 00.19 | AS | 0 | E | I | 266-03 | Due to disturbance of coolant instrumentation |
| 08 May | 01.04 | 17.53 | 17.57 | 18.09 | 00.04 | 00.16 | AS | 0 | E | I | 267-01 | Due to disturbance of coolant instrumentation |
| 13 May | 01.04 | 03.37 | 03.41 | 03.51 | 00.04 | 00.14 | AS | 0 | E | I | 266-02 | Due to disturbance of coolant instrumentation |
| 24 May | 01.05 | 13.00 | 17.15 | 18.45 | 04.15 | 05.45 | MS | 0 | E | R | 336-01 | Due to experimental requirements (temperature excursion) |
| 25 May | 01.05 | 00.01 | 00.06 | 00.19 | 00.05 | 00.18 | AS | 0 | E | I | 267-02 | Due to disturbance of coolant instrumentation |
| 27 Jun | 01.06 | 20.27 | 20.31 | 20.44 | 00.04 | 00.17 | AS | 0 | E | I | 267-01 | Due to disturbance of coolant instrumentation |
| 02 Jul | 01.06 | 14.27 | 14.34 | 14.44 | 00.07 | 00.17 | AS | 0 | E | I | 266-02 | Due to disturbance of coolant instrumentation |
| 10 Aug | 01.07 | 11.29 | 11.49 | 11.57 | 00.20 | 00.28 | MP | 30 | E | R | 347-01 | Unloading of experiment INCOMODO with targets |
| 16 Aug | 01.07 | 17.15 | 17.47 | 17.52 | 00.32 | 00.37 | MP | 30 | E | R | 347-01 | Loading of experiment INCOMODO with dummies |
| 16 Aug | 01.07 | 19.05 | 19.09 | 19.18 | 00.04 | 00.13 | AS | 0 | R | H | 292-01 | Wrong action taken during experiment handling |
| 18 Sep | 01.08 | 18.58 | 19.02 | 19.09 | 00.04 | 00.11 | AS | 0 | E | I | 347-01 | Due to disturbance of coolant instrumentation |
| 09 Oct | 01.09 | 18.59 | 19.03 | 19.24 | 00.04 | 00.21 | AS | 0 | E | H | 267-03 | Wrong activation of safety system |
| 06 Nov | 01.10 | 10.11 | 10.11 | 10.12 | 00.01 | 00.01 | MP | 41 | E | H | 292-02 | Action taken during handling with experiment |
| 16 Nov | 01.10 | 14.49 | 14.57 | 15.15 | 00.08 | 00.26 | AS | 0 | R | E | Mains outage | Due to a electrical disturbance of mains supply |
| 16 Nov | 01.10 | 15.37 | 15.43 | 15.15 | 00.06 | 00.18 | AS | 0 | R | E | Mains outage | Due to a electrical disturvance of mains supply |
| 17 Nov | 01.10 | 10.20 | 10.21 | 10.23 | 00.01 | 00.03 | MP | 35 | E | H | 292-02 | Action taken during handling with experiment |

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

## HFR WASTE POLICY

As with other nuclear installations, a research reactor produces nuclear waste. The policy of the HFR is to clear all waste and to store it under permanent storage at a dedicated site in the Netherlands, under Dutch technical regulations. This policy was defined only several years ago, prior to which the waste was stored in dedicated places on the Petten site.

The application of this “new” policy has to be made not only for the current day-to-day waste production, but also for the accumulated waste since reactor operation began in 1961.

Firstly, work began and has since been completed with the removal of all the low and medium active waste that had accumulated over the years. The day-to-day production is being sent regularly (about one transport per month) to the COVRA site, for permanent storage under Dutch regulations.

For the high radioactive waste (HRW) (spent fuel and some irradiated components) a dedicated building called HABOG has been designed not only for HFR, but also for all other Dutch nuclear facilities. The building works began in 1999 and should be available for loading tests in 2003. This facility will allow the storage of the HFR spent fuel in dedicated canisters and of the HRW.

This waste will be transported in MTR-2 containers to COVRA and repacked in dedicated storage containers in the HABOG building. The HFR annual production is about 10 barrels and 60 elements per year. The volume of HABOG will allow in the future the storage of all the waste of the past and of all the waste to be produced by HFR until the date of 2015.

The loading of HABOG will start with tests in 2003, then waste storage starting during the next HFR programmes 2004/2007 and will continue at least until 2014 with the objective to have received all the waste during this period.
During 2001, studies were made on a dedicated hot cell on the Petten site to prepare all the existing waste (by cutting, separating, compacting, etc.) to optimise the transfer to the COVRA site, as soon the HABOG facility becomes available. In the meantime, the 4 MTR2 container transportations made in 2000 have shown the feasibility of this transfer operation.

In conclusion all the operations related to HFR waste have been identified, which will allow us to reach our objectives for permanent storage of all the HFR waste – past and future – on the COVRA site.



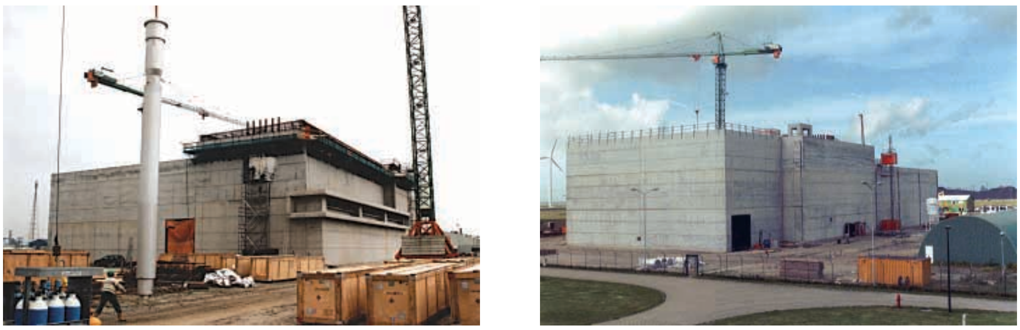


Figure 4: HABOG facility under building in 2001

# SAFETY AND QUALITY MANAGEMENT

## SAFETY

### Plan for a new HFR licence

After a period of approximately four decades of uninterrupted operation of the HFR in Petten, JRC, as licensee and NRG, as operator, agreed with the Dutch nuclear regulators to start in 2000 a programme to renew the licence of the HFR.
In this frame, seven actions have started:

- The HFR conversion study: all aspects of the conversion of the core from HEU charging to LEU charging.
- The Risk Scoping Study: the probabilistic safety analyses
- Analyses: analyses of the set of Postulated Initiating Events that envelop the entire programme of design base accidents the reactor systems have to deal with.
- Ageing: the research programme on ageing and deterioration of materials due to radiation exposure.
- The Safety Evaluation: the evaluation of the existing plant against the current licensing base and today's safety standards and safety philosophy.
- The Safety Report: the production of the Safety Report being one of the main documents for the licensing procedure.
- The MER procedure: the assessment of the environmental impact of envisaged activities and their possible alternatives.

## PIE

The aim of the Postulated Initiated Event analysis is to check that the HFR meets the thermal-hydraulic, reactivity and radiological success criteria of a set of enveloping design base accidents.
A list of PIE's has been developed and the enveloping ones have been selected and justified for analysis. Based on the requirements of the current safety standards, a set of PIE's that the HFR has to manage has been established first. Plant and site specific issues and circumstances have been taken into account. Next the methodology for selection of the initiating events has been clarified. For the selection (inter-) national standards and HFR specific practices a/o have been considered. Finally the justification of the enveloping initiating events has been established.
In the next step, the methodology for the analyses of the enveloping PIE's has been determined, including the acceptance criteria for the thermal-hydraulic-, reactivity- and radiological analyses, the initial and boundary conditions for each of the enveloping PIE's and the computer codes to be used.

- **Loss of flow**
  - Primary pump failure
  - Primary coolant flow reduction
  - Influence of experiment failure or mishandling
  - Emergency cooling system failure
  - Primary coolant boundary rupture leading to loss of flow
  - Fuel channel blockage
  - Coolant reduction due to core bypass
  - Loss of heat sink
- **Insertion of excess reactivity**
  - Criticality during fuel handling
  - Startup accident
  - Control rod or control rod follower failure
  - Control drive or system failure
  - Unbalanced rod positions
  - Cold water insertion
  - Influence by experiments and experimental facilities
  - Insufficient shutdown reactivity
  - Inadvertent control rod ejections
- **Special internal events**
  - Internal fires or explosions
  - Internal flooding
  - Loss of support systems
  - Security incidents
  - Reactor experiment malfunctions
  - Improper access to restricted areas
- **Human errors**
- **Erroneous handling or failure of equipment or components**
  - Fuel element cladding failure
  - mechanical damage to core fuel
  - Criticality of fuel in storage
  - Containment or ventilation system failure
  - Loss of coolant to fuel in transfer or storage
  - Loss or reduction of proper shielding
  - Failure of experimental apparatus or materials
  - Exceeding fuel ratings
  - Insertion of excess reactivity
- **External events**
  - Earthquake
  - Flooding
  - Tornadoes and tornado missiles
  - Hurricanes, storms and lightning
  - Explosions
  - Fire
  - Toxic spills
  - Transport route accidents
  - Influence from adjacent facilities
- **Loss of coolant**
  - Primary coolant boundary rupture
  - Damaged pool
  - Pump -down of pool
  - Failure of beam tubes or other penetrations
- **Loss of electrical power supplies**
  - Loss of normal electrical power

Figure 5: Postulated Initiating Events for the reactor

## Activities for the HFR core conversion to Low Enriched Uranium

Taking into account the need to assure the HFR fuel cycle as well as the public and political opinion being strongly in favour of conversion, the decision was made by the European Commission to convert the HFR core to Low Enriched Uranium (LEU).

Following this decision a project was started for the conversion consisting of 3 phases, i.e.:

- Phase 1: Parametric study to define the optimum LEU-element (fuel element and control rod).
- Phase 2: Technical qualification of the conversion.
  Phase 3: Review and update of licence reference study.

The three-phase approach was submitted to the Dutch Competent Authorities and consent was granted.

Phase 1 “Parametric study” was performed by experts of Argonne National Laboratory (Argonne, USA) and Nuclear Research and consultancy Group (NRG) and has resulted in the optimum HFR LEU design including technical parameters such as:

- Type and density of fuel (4.8 g.cm-3 U3Si2)
- Number of fuel plates per element (20/ 17 for a FE/CR)
- Thickness of fuelled meat and cladding (0.76 and 0.38/ 0.57)
- Type and amount of burnable poison (Cd-wires diameter 0.5; length 625 mm)

As boundary conditions for phase 1 the following objectives were agreed upon:

- Progressive core conversion for economical reasons
- Geometry of fuel elements and control rods consistent with HEU design to enable the progressive conversion
  Minimal changes of the fuel cycle costs
- Minimal penalties on thermal fluence rate (in-core and PSF)
- Short planning and implementation programme

The outcome and the boundary conditions of phase 1 are used as input data for phase 2 "Technical qualification of the conversion".

Due to the complexity of phase 2 as well as the variety of aspects to be covered within this technical qualification, it was agreed with the competent authorities to divide phase 2 into 9 different activities:

- Neutronic calculations
- Review of hydraulic pressure drop
  Thermo-hydraulic calculations
- Bibliographic review of fuel behaviour (literature study)
- Mechanical consequences of conversion
- Consequences on experiment behaviour/safety
- Consequences on the fuel cycle
- Consequences on the incident and accident calculations
- In-pile testing of two LEU fuel elements

The calculational results and theoretical considerations per activity are used in the course of phase 3 “Review and update of licence reference study”.

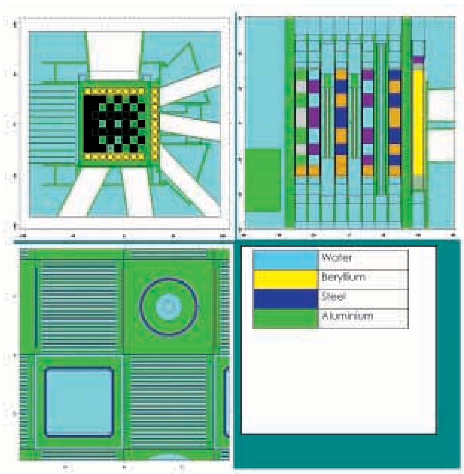



Figure 6: Horizontal and vertical cross-sections of the MCNP model of the HEU core (REBUS computer code)

## HFR MAINTENANCE AND UPGRADING

Apart from the regular preventive maintenance, which is carried out according to standard procedures, and the corrective maintenance, the main activity in 2001 consisted of the in service inspection of the reactor vessel.

**In-Service Inspection:** The regular visual and ultrasonic inspection of the reactor vessel was carried out during the summer stop of 2001. Visual inspection was performed using an underwater camera for part of the welds of the reactor vessel and for internal and external components. Geometrical measurements of the core box and of the upper and lower plenum of the reactor vessel revealed no significant deviations compared to measurements conducted in 1984 on the new vessel.

Figure 7: In-Service Inspection of the reactor vessel

Ultrasonic inspection was performed using a more sophisticated measurement and evaluation technique than that used in the past. This has resulted in more accurate measurements and a reduced duration of the inspection, which allowed to limit the duration of the summer stop to 3 weeks. As expected beforehand, the new technique has provided more information on known defect indications, particularly for one of the welds. A local lack of fusion inside the weld material, already detected as a fabrication defect during the pre-service inspection of the vessel in 1984, has now been shown to consist in fact of two smaller defects located next to each other. At the request of the Dutch authorities fracture mechanics analyses have been performed which indicated that the envelope defect is stable and that there is no risk of further evolution. To confirm this conclusion an additional ultrasonic inspection for this particular weld defect based on the same technology will be performed in 2002.

**Informatics network:** The main part of the computer network as well as the telephone network has been renewed. The new network allows a faster data transfer and provides an increase in functionality. The prime qualities of the structured cabling system are consistency, flexibility and a structured design formula. It includes two patch panels in a star topology. Each office with telephone, PC, printer, etc can now be connected with the ECN/NRG network and the two JRC networks. In the new configuration, the BNCT wing is also connected by a fibre connection.

**Chlorine close system:** In order to eliminate macro and micropollution of the system and components of the secondary cooling water system by microbes and other organic creatures, chlorine is added in the secondary pump building. The extent of macro and micropollution is a function of the temperature of the secondary cooling water. The higher the intake temperature of this water, the greater the pollution. A study has been started to determine the minimum amount of chlorine needed throughout the year. Measurements of fouling are made inside the secondary pump building and inside the primary heat exchangers by means of fouling monitors. These measurements and analyses will continue in 2002 and ultimately will result in a decrease of the amount of chlorine being used.

Figure 8: Ultrasonic In-Service Inspection

## FUEL CYCLE

**Front End:** Following the decision taken in 1999 to convert the HFR to low enriched uranium (LEU) fuel and the exchange of diplomatic notes in January 2000 between the European Commission and the United States authorities concerning the conversion of the HFR to low enriched fuel and interim supply of high enriched uranium (HEU) from the US, an export licence was obtained from the US Nuclear Regulatory Commission allowing HEU supply from the US to fuel the HFR for a period of four years. In early autumn 2000 a first quantity of HEU was shipped in several batches to the fuel manufacturer. These shipments had to be interrupted because the licence of the transport container expired. After renewal of the container licence the remaining quantity of the supply authorised for the year 2000 was shipped in early 2001. Following an amendment of the export licence issued by the US Nuclear Regulatory Commission the full amount of the HEU supply for the year 2001 was shipped in a single transport in spring 2001.

During the year 2001 new fuel elements and new control rods were inspected at the manufacturer's site and delivered on schedule. A new order for manufacture and delivery of fuel elements and control rods was placed.

Good progress was made in 2001 with the studies on the conversion of the HFR to LEU fuel. The second phase of these studies was completed. Furthermore a prototype LEU fuel element was ordered for delivery and subsequent testing in 2002.

Figure 9: Arrival of HFR spent fuel at the port of Den Helder for shipment to the United States

**Back End:** In autumn 2000 four MTR-2 containers with HFR spent fuel were successfully shipped to the central organisation for radioactive waste in the Netherlands, COVRA. These containers with spent fuel are being temporarily stored at the COVRA site awaiting unloading and transfer of the spent fuel to the HABOG facility for long term storage. The MTR-2 containers are designed for both transport and storage of spent fuel. The HABOG facility at present under construction at the COVRA site is scheduled to become available for storage of spent fuel and highly radioactive waste after mid-2003.

After the above-mentioned shipments to COVRA further removal of HFR spent fuel was necessary to ensure continuation of reactor operation. Following the exchange of diplomatic notes between the European Commission and the United States authorities concerning conversion of the HFR to LEU fuel the option to return spent fuel of US origin to the US became also available. Since the Dutch Ministry for Housing, Spatial Planning and the Environment granted additional funding for a shipment of about 120 HFR spent fuel sections to the US, preparations for such a shipment were started in 2000. In early 2001 contracts were signed with the transporter and with the US Department of Energy (DOE). Three transport containers were loaded with 117 spent fuel sections in April / May 2001 and transferred to the port of Den Helder in the Netherlands on the 1st June 2001 for shipment to the United States. At the end of June, the spent fuel arrived safely at DOE Savannah River Site. As a result of this shipment sufficient storage capacity became available in the HFR pools to allow reactor operation until 2003.


Figure 10: Container with HFR spent fuel placed on board of the vessel for shipment to the United States

# HFR: The Programmes

## HFR AS A TOOL FOR EUROPEAN PROGRAMMES

### AMES

**Ageing Materials European Strategies**
The Institutional Project AMES is the framework for activities aimed to understand, monitor, predict and mitigate the degradation of critical materials in view of plant life management of primary component of nuclear reactors. Western and eastern types of steels are involved in the various activities. The various activities are undertaken as international co-operation projects with key players in Western Europe, PECO and NIS countries. In 2001 activities have developed towards the Accreditation of the AMES Laboratory to ISO 17025 Standard. The Institutional Project is subdivided into several tasks as shown below:

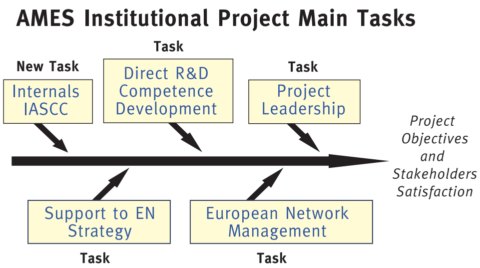



Figure 11: AMES Institutional Project Main tasks Figure

**Direct Research & Development**
A R&D Task is maintained in order to produce JRC original results and ideas on the topic and to develop deep knowledge on the related issue: including studies on model alloys and commercial steels, the development of non destructive methods to monitor material degradation, development and operation of suitable dedicated irradiation facilities and programmes at the High Flux Reactor, etc.

The research on "Model alloys" has continued during 2001. The study has been completed with results on positron annihilation and internal friction measurements.

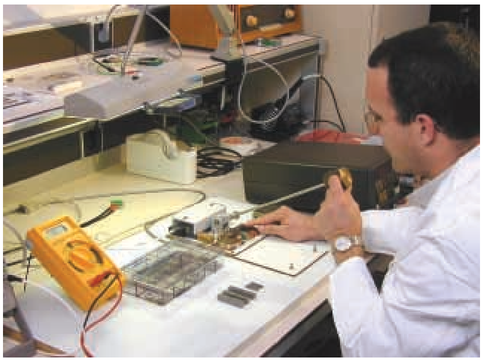


Figure 12: Sample measurement using STEAM prototype

New model alloys to be employed in ATHENA task E have been received and characterised at the Impact Laboratory [24] & [25].

Regarding the Impact Laboratory performance, a total of 273 samples (full size and miniaturised Charpy V-notch) have been processed in 2001. With its Hardness Vickers 10 machine and its Impact hammers, the laboratory has also provided support to other JRC-IE's projects, such as SPEECH and NESC [28].

Figure 13: AMES Impact Testing Facility – 300J Hammer

**European network management & support to European Network Strategy**
A fundamental task of the project is the management of the AMES European Network. The AMES (Ageing Materials European Strategy) European Network started its activity in 1993 with the aim of studying ageing mechanisms and remedial procedures for structural materials used for nuclear reactor components. Operated by JRC-IE, this network has developed to include all key players in Western Europe and candidate countries and has developed strong connections with NIS countries like Russia, Ukraine and Armenia. [17].

An important task of the project is the support of the European Network strategy. Such a task, implies the development and maintenance of the network strategy and the pro-active management of a relevant project portfolio of Shared Cost Activities, the provision of reference materials and methods, the dissemination of results and, of course, including the access of partners to JRC facilities, e.g. HFR-LYRA and AMES laboratory.

AMES supports the co-ordination of the project cluster throughout the 4th and 5th EURATOM Framework Programmes, carrying out projects with plant life management implications, including the development of non-destructive techniques applied to thermal ageing and neutron embrittlement monitoring (AMES-NDT and GRETE); improved surveillance for VVER 440 reactors (COBRA); dosimetry (AMES-DOSIMETRY, MADAM and REDOS); chemical composition effects on neutron embrittlement (PISA); and advanced fracture mechanics for integrity assessment (FRAME) [29] & [30].

The technical and strategic Task Groups of AMES are the following:

TG A: Linking National and AMES strategies
TG B: Linking AMES Strategy with Eastern Europe (EPLAF)
TG C: Master Curve implementation for fracture toughness assessment
TG D: Annealing and re-embrittlement issues
TG E: Radiation embrittlement understanding
TG F: Ageing mechanisms: influence and synergism
TG G: Watch-and-alert (IASCC, NDT, ...)

The Task Groups of AMES are part of the ATHENA concerted action.

**Internals IASCC**
Recently, more and more issues related to reactor internals are surfacing, in particular the issue of IASCC (Irradiation Assisted Stress Corrosion Cracking). Consequently, the new group of activities that have been added to AMES on such issues continue to give a comprehensive view on safety of the primary loop of nuclear reactors.

**AMES Achievements 2001**
performed successfully:

- Settlement of the Magnetic Laboratory, including provision of necessary equipment (i.e. gaussmeter, hysterisis graphs, etc.) and demonstration tests.
- To validate the magnetic measurement technique a benchmarking exercise between JRC-AEKI and IZFP Fraunhofer took place in September 2001 [18] & [19].
- Full statistical analysis of measurement data from the thermoelectric power device, STEAM, and correlation with resistivity measurements [20] [22] & [23].
- In view of accrediting the STEAM technique a set of operation guidelines and the measurement procedure have been made [21].
- In 2001 a new investigation on steel coming from a mock-up of VVER-1000 reactor pressure vessel has been started under the sponsorship of AMES and the IAEA. Blocks of such material have been distributed through different research institutes in Bulgaria, Hungary, Czech Republic, Ukraine and India[26].
- IAEA representatives attended the AMES Network Steering Committee meetings in 2001. Active involvement in IAEA CRP Programmes on “Validation of Surveillance Programmes”, and on “High Nickel VVER steels” of which AMES has become custodian of the reference material.
- Launch of the ATHENA Thematic Network dedicated to ageing issues in NPP’s.

- Start of PISA (Phosphorus Influence on Steel Ageing) and REDOS (Reactor Dosimetry: Accurate determination and benchmarking of radiation field parameters, relevant for reactor pressure vessel monitoring) Shared Cost Actions.

**Other activities**

*Co-operation with IAEA*

Solid co-operation is in place; JRC takes part in several related IAEA activities, round-robin and co-ordinated research projects, as the CRP on Master Curve [31] & [32].

In August 2001, 1.3 tons of steel blocks coming from the IAEA were received [27]. AMES will characterise and guard the material until its distribution is decided within the IAEA High Nickel steel programme.

*R&D support to TACIS*

The AMES project is also complementing the Institute support service in the TACIS programme, in particular in the field of radiation embrittlement and related research projects.

Figure 14: VVER 1000 Reference Steel for IAEA/JRC Co-operation programme

**The AMES Network Consortium**

The AMES network is driven by the following nuclear power plant utilities, industrial companies, research centres and universities of the European Union and Candidate Countries:

AEA Technology, United Kingdom
BNFL Magnox, United Kingdom
LMD, UK
TRACTEBEL, Belgium
SCK/CEN, Belgium
NRG, the Netherlands
MPA Stuttgart, Germany
Framatome ANP GmbH, Germany
FZR, Germany
CEA, France
EdF, France
VTT, Finland
Fortum, Finland
Tecnatom, Spain
CIEMAT, Spain
Empresarios Agrupados, Spain
Pisa University, Italy
SKI, Sweden
NRI Rez, Czech Republic
VUJE, Slovak Republic
IMS, Bulgaria
AEKI, Hungary
DG Joint Research Centre, European Commission
DG RTD, European Commission
DG TREN, European Commission

More information about AMES can be found on:
AMES Internet site (www.jrc.nl/ames/)
CIRCA (www.forum.europa.eu.int/jrc/)

AMES web pages are regularly updated and maintained. Most of the AMES reports can be downloaded from the Internet. The pages of ENUKRA and IRLA Projects have been completed and new projects (GRETE, COBRA, FRAME and PISA) have been added in the main page.

## EFTTRA

**Transmutation of Fission Products and Minor Actinides**

**Background:** Recycling of actinides and long-lived fission products is an option in the management of high level nuclear waste from current nuclear power reactors in reducing significantly the long-term radiological activity.

The recycling process involves the separation, besides uranium and plutonium, of the 'Minor Actinides' (Np, Am, Cm) and some long-lived and mobile fission products (e.g. Tc, Cs, Np and I) from spent nuclear fuel (Partitioning), followed by subsequent re-irradiation (Transmutation or Incineration).

Major international programmes have been initiated world-wide to study whether advanced reprocessing with Partitioning and Transmutation (P&T) can become an alternative to the existing strategies of high level fuel management, being direct disposal and reprocessing.

The HFR is involved by the French supplementary programme in technological studies of P&T for the European collaboration group called EFTTRA [65].

EFTTRA is a collaboration agreement of six research organisations, namely CEA (France), NRG (The Netherlands), EdF (France), FZK (Germany), JRC-ITU and JRC-IE that was launched in 1992. The goal of EFTTRA is the joint study of transmutation of americium and of long-lived fission products technetium (99Tc) and iodine (129I). The work of the partners of the EFTTRA group is focused on the development and testing of targets and fuels, taking into account the scenarios developed in Europe for possible P&T strategies. Irradiation experiments are being performed in parallel in the HFR Petten and in the Phenix fast reactor.

**Status:** Up to now, seven EFTTRA experiments have been successfully performed in the HFR [63] & [64]. In 2001, a proposal was prepared for the continuation of the EFTTRA-T4 programme with the EFTTRA-T5 experiment. Irradiation of EFTTRA-T5 is planned for 2003-2004. It will contain four Cer-Cer targets with americium, see [64].

## HTR-TN - High Temperature Reactor Technology Network

The High Temperature Reactor Technology Network (HTR-TN) was founded in April 2000 by a large number of the partners of the cluster of HTR projects of the 5th EURATOM Framework Programme and by the Joint Research Centre (JRC) of the European Commission, which is operating agent of the network.

The institutional project was then started with the goal of supporting the network organisation, strategy and experimental needs concerning the High Flux Reactor, structural materials and database support.

**Background**

New generation modular high temperature gas reactors should provide a safe and efficient way to minimise waste and burn military grade plutonium. Nuclear gas reactor technology in Europe is at present still exploited in UK, whilst about twenty years ago considerable progress and investments were made in Germany and also other European countries.

Under the auspices of a renovated worldwide interest for this technology, European nuclear industries and research organisations decided to collaborate in the HTR-TN.

The international involvement is led by Japan, China and South Africa, who already run or are developing prototype reactors, but also USA and the Russian Federation with their GT-MHR (Gas turbine modular high temperature reactor) design and non-proliferation programme, supported by the EU. The IAEA is also organising a new coordinated research programme (CRP) on HTR-fuel, managed by the HTR-TN fuel task group leader. In the frame of generation IV actions, a dedicated group on gas-cooled reactors is also operating and followed by the HTR-TN vice-president.

**Networking objectives**

The general objective of the network is the co-ordination and management of expertise and resources in developing advanced HTR technologies. The network helps the European nuclear industry in designing reactors of this type, which can withstand in the long term the competition of other sources of energy, while keeping a very high level of safety and offering innovative solutions for minimising the long lived high level wastes of the fuel cycle and for burning civil and military plutonium in a particularly efficient way.

The primary focus is to recover and make available to the European nuclear industry the data and know-how already accumulated in the past in Europe and in other parts of the world, concerning the development of HTR technology.

The ultimate goal is the development of advanced technologies for modern HTR's, in order to support the industry for the design of reactors, which can fulfil in a sustainable way economic competitiveness and social acceptability.

**HTR-TN members**

With several new members, the membership at the end 2001 was the following:

ANSALDO, Italy
BDT, Germany
BELGATOM, Belgium
BNFL, UK
CEA, France
CIEMAT, Spain
COGEMA, France
EdF, France
Empresarios agrupados, Spain
FRAMATOME ANP SAS, France
FRAMATOME ANP GmbH, Germany
FZ Jülich, Germany
IKE, Germany
IPM Zittau, Germany
IRI Delft, The Netherlands
NNC, UK
NRG, The Netherlands
VTT, Finland
VUJE, Slovakia

The organigramme showing the related organisation and task groups is given in Figure 15.

## HTR-TN Organigramme

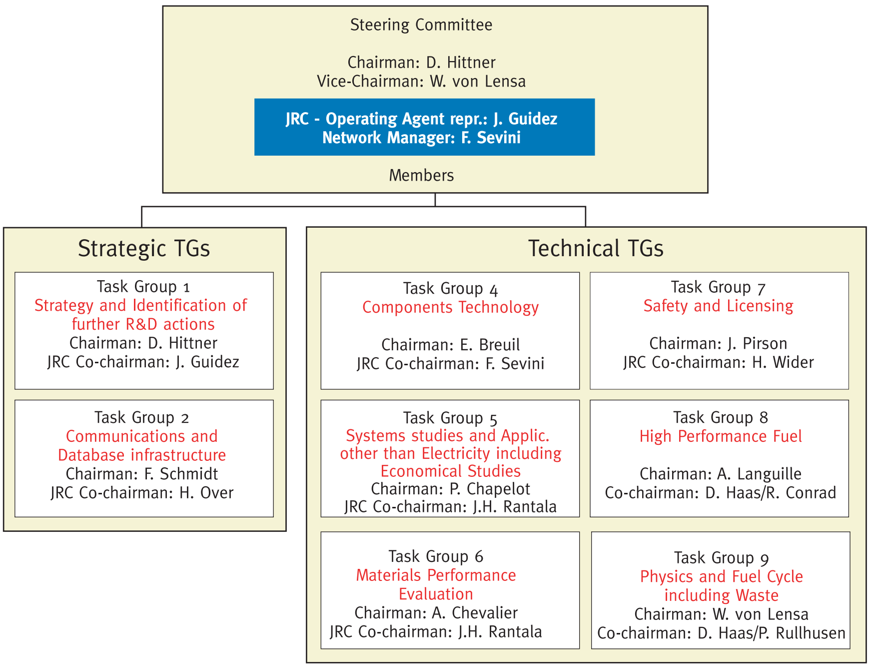



Figure 15: HTR-TN organigramme

## Achievements in 2001

- The 6 projects listed in Figure 16 are operating for a total budget of 16.9 M euro.
- Extensive support to the development of the network and its task groups
- Conception and design of the HFR fuel irradiation rig for HTR-F.
- Support to structural material testing and characterisation for HTR-M.
- Support and development of web data platforms.
- Development of the network web page.
- Development of contacts and collaboration agreements with Chinese, Japanese and Russian organisations with running HTR prototypes or related HTR projects.
- Fuel seminar in Brussels, Feb 2001.
- Preparation of a road map on HTR-TN development in FP6.
- Study of test irradiations on vessel material and graphite (for HTR-M).
- Preparation of the first international topical meeting on HTR technology to be held in Petten, in April 2002 (call for papers and preliminary programme.

**HTR - related projects sponsored under Euratom FP-5**

| Acronym | Title | Co-ordinator | Nbr. of Partners | Duration (months) | EC Funding |
|---|---|---|---|---|---|
| HTR-F<br>HTR-F1 | *HTR Fuel Technology* | *CEA (F)* | *7* | *48* | *1.7 M€*<br>*0.8 M€* |
| HTR-N<br>HTR-N1 | *HTR Reactor Physics and Fuel cycle* | *FZJ (D)* | *14* | *54* | *1.0 M€*<br>*0.55 M€* |
| HTR-M<br>HTR-M1 | *HTR Materials* | *NNC Ltd (UK)* | *8* | *54* | *1.1 M€*<br>*0.7 M€* |
| HTR-E | *HTR Component and systems* | *Framatome (F)* | *14* | *48* | *1.9 M€* |
| HTR-L | *HTR Safety Approach and Licensing main issues* | *Tractebel (B)* | *8* | *36* | *0.5 M€* |
| HTR-C | *Project Co-ordination* | *Framatome (F)* | *6* | *54* | *0.2 M€* |
| | | ***TOTAL:*** | | | ***8.45 M€*** |

Figure 16: HTR related projects

# HTR 2002

Organised by the European Nuclear Society (ENS)
in cooperation with the the Joint Research Center (JRC), Petten
and the International Atomic Energy Agency (IAEA)

1st International Topical Meeting

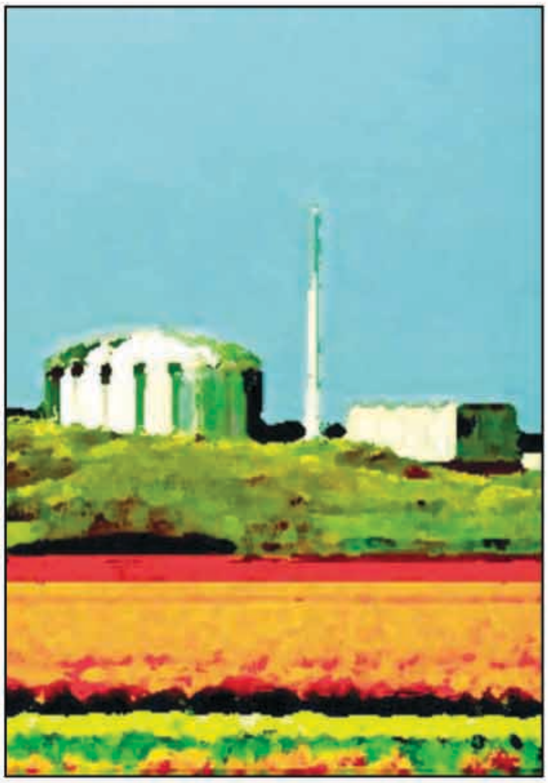
## High Temperature Reactor Technology (HTR)

Petten, Netherlands, April 22–24, 2002

## PRELIMINARY PROGRAM

HTR-TN

High Temperature Reactor Technology Network



For several years there has been a renewed world-wide interest in High Temperature gas-cooled Reactors (HTR). Their inherent safety features, potential for use in high temperature industrial processes, and the possibility of using direct cycle gas turbines have made HTRs a very attractive concept in the current socio-economic and political environment and also as a 4th Generation candidate. Two research demonstration reactors – the HTTR (Japan) and the HTR-10 (China) – have recently attained initial criticality and have started ambitious experimental programmes. In addition, two different prototype reactors are in the detailed design phase – the PBMR (South Africa) supported by a consortium of organisations from South Africa, UK and US, led by ESKOM, and GT-MHR supported by a consortium of organisations from US, Russia, Japan and France. In the EU, the EC is sponsoring research on HTR in its 5th Euratom Framework Programme and a strong network (HTR-TN) has been set up to co-ordinate and manage the expertise and resources of participant organisations.

The objective of this meeting is to establish a dedicated forum of experts for this emergent technology. It will also promote and stimulate international collaborations among public and private organisations to avoid duplication effort and to use available resources in the most efficient way.

### Proven formula

A 3-day IAEA meeting on HTR entitled “High temperature gas cooled reactor applications and future prospects” has already been held at Petten in November 1997 and attracted participants and observers of ten countries, thus many of the experts in the field are already familiar with the venue.

### Programme

The three-days HTR 2002 will feature a limited number of invited papers and ample space for the presentation of contributed papers ,both orally and as posters:

- fuel and fuel cycle
- physics and neutronics
- thermohydraulic
- engineering,design and applications
- material and components
- safety and licensing

### Venue

HTR will be held in the conference room at Petten site, located near the North Sea. The conference dates are situated in the middle of the world-renowned Dutch “flower season”, so due to intense touristic activity, it is asked that candidates respect the dates of pre-registration – hotel reservations could be difficult or impossible after this date.

The venue is easily accessible from Schiphol airport (Amsterdam) by motorway (about 60 km). Local attractions include the place of Keukenhof, which is Holland's major flower attraction. For eight weeks, millions of flowers in all colors of the rainbow decorate this 32-hectare park. Other nearby attractions and areas of interest are the navy museum and the departure point to the Texel islands in the town of Den Helder, the many flower attractions in this area of North Holland, as well as the two famous cities of Amsterdam and Haarlem, which are nearby and within easy access.

# NET-EUROPEAN NETWORK ON NEUTRON TECHNIQUES STANDARDISATION FOR STRUCTURAL INTEGRITY

The aim of NET is to support progress towards improved performance and safety of European energy production systems through the standardisation and harmonisation of neutron based NDT methods within the enlarged EU and to provide a forum for training of young scientists, and sound advice to the EC policy makers.

**Background**

A key aspect in the life assessment of structural components is the development and harmonisation across Europe of relevant advanced measuring techniques. IE has launched a new institutional research project entitled NET - Network on Neutron Techniques Standardisation for Structural Integrity. NET focuses on the development and standardisation of NDT methods based on neutron diffraction for structural integrity of nuclear safety related components. Neutron beam based NDT methods such as diffraction; small angle neutron scattering and radiography are very suitable for the assessment of microstructure, defects and internal stress in welded structures. While in the last decade a lot of research work has been conducted in the development of these techniques, it is only recently that serious effort toward their standardisation has been undertaken.

## NET Objectives

- Performance and safety enhancement of European Nuclear Power production by supporting the structural integrity and the safe operation of ageing reactors, and neutron research.
- Promotion of the nuclear energy production safety and neutron research culture within the enlarged EU.
- Development, standardisation and harmonisation of NDT based on neutron methods (neutron diffraction, small angle neutron scattering - SANS - and neutron radiography), with an application to structural integrity throughout the enlarged EU. (Development and performance of round robin campaigns, contribution to current and future CEN activities, drafting of handbooks of best practice).
- Development of harmonised procedures, accepted by industry and regulators, for reliable evaluation of residual stress, microstructure and defects and procedures for incorporating them in structural integrity assessment.
- Interaction with other nuclear Networks, such as AMES, ENIQ and NESC and support to NET related competitive activities, such as INTERWELD, ENPOWER and ADIMEW, concerning investigations of materials ageing, structural integrity and NDE for welded RPV internals and primary piping joints.
- Training of young scientists in neutron techniques through the development of a European Training Network comprising several Neutron Facilities and other partners as necessary.

## NET related HFR facilities

The HFR neutron beam facilities have enabled JRC to play a leading role in the development and standardisation of neutron methods at European and International level. Three neutron diffractometers - HB3a, HB4 and HB5 - are used for microstructure, texture and stress investigations in structural components. HB3b and HB8 are used for defects analysis based on small angle neutron scattering and radiography respectively. These facilities support several IE institutional and competitive research activities.

## Standardisation Activities

Based on the outcome of the VAMAS TWA 20 and RESTAND projects a joint CEN/TC 138- ISO/TC 135 group of experts (AHG 7) has been formed, which is charged with the development of an International Technical Specification on “test method for determining residual stress by neutron diffraction”. Furthermore, the draft standard document developed within RESTAND and VAMAS TWA 20 has been published as an International Standard Organisation Technology Trends Assessment document (ISO/TTA) [45]. JRC convened the AHG7 kick-off meeting in April at Petten. The second experts group meeting was held at N.C.S.R.-DEMOKRITOS in Athens in September 2001. It is expected that by end 2003 the document should be finalised to be submitted to ISO and CEN members for adoption by end 2004.

| Shared Cost Activities | Partners |
|---|---|
| HITHEX<br>INTERWELD<br>ENPOWER<br>ADIMEW | SKT (D),<br>DLR (D),<br>INASCO (GR),<br>NMC (UK),<br>CEA (F),<br>ENEA (I),<br>IMP/CNRS (F),<br>MPA (D),<br>ANSALDO (I),<br>SEIBERSDORF (A) |
| | NRG (NL),<br>FRAMATOME (D),<br>CIEMAT (E),<br>SCK-CEN (B),<br>PSI (CH) |
| | IdS (F),<br>USINOR (F),<br>British Energy (UK),<br>MBEL (UK),<br>Un. of Bristol (UK)<br>FRAMATOME-ANP (D) |
| | EDF (F),<br>VTT (FIN),<br>TWI (UK),<br>CEA (F),<br>FRAMATOME (F),<br>SERCO ASSURANCE (UK) |

Table 3: Net related running SCA’s and involved partners

## Competitive activities

The RESTAND project has been completed and characterised as one of the DG RTD SMT Programme success stories. Three competitive activities initiated in 2000 were continued throughout 2001, i.e., ADIMEW, INTERWELD and HITHEX.
A new DG RTD NFS Programme funded project - ENPOWER - was started in December 2001.

## RESTAND

The final RESTAND project meeting was held in Petten in February 2001 and its 3rd annual report along with its main deliverable, i.e., the draft standard document, and the final Project Quality Indicators (PQI) form were submitted to DG RTD in July 2001. During the last project year, JRC performed measurements on various VW crankshaft sections related to the testing and evaluation task of the project (Task 7). A comparison of these experimental data with similar data derived by VW based on numerical modelling is shown in Figure 17.

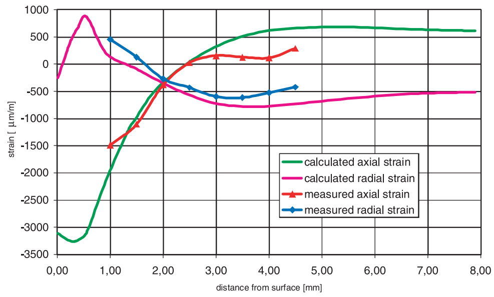



Figure 17: Experimental and numerical strain data obtained for a deep rolled, induction hardened crankshaft section

**ADIMEW** – Assessment of Aged Piping Dissimilar Metal Weld Integrity

This project is in effect an offshoot of BIMET. The major difference is the piping thickness and diameter. JRC (HFR) is responsible for the residual stress mapping in the austenitic/ferritic steel-piping weld, using neutron diffraction. Planning for monitoring of strain and temperature during welding deposition as well as adjusting the welded component dimensions have been completed.

**INTERWELD**-Irradiation Effects on the Evolution of the Microstructure, Properties, and Residual Stresses in the Heat Affected Zone of Stainless Steel Welds

The project programme calls for assessing the evolution of microstructure and internal stress in irradiated weld specimens simulating RPV shroud weld irradiation during reactor operation. Within INTERWELD, JRC (HFR) is responsible for residual stress analyses in irradiated and unirradiated specimens based on neutron diffraction. Preliminary testing on unirradiated specimens has been carried out with variable degrees of success. In the context of envisaged investigations on irradiated specimens, a suitable hot cell is under preparation.

**HITHEX** - Prediction of the Lifetime Behaviour for C/C-SiC Tubes as High and Ultra-high Temperature Heat Exchangers

This project is building on the conclusions of the completed UHTHE project. Its objective is to contribute to the development of long fibre reinforced ceramic matrix material based tubes capable to withstand ultra high temperature operating conditions. JRC (HFR) is responsible for the assessment of residual stresses, based on neutron diffraction, induced by various manufacturing processes pursued within this project. In the course of 2001 it has been possible for the first time, to assess 3-D residual stress levels thanks to the availability of suitable reference materials for the SiC matrix and Si. It was established that the SiC matrix of the tested tubes exhibited large internal stresses in the range of 200-250 MPa in the hoop and axial directions respectively, while stresses in the radial direction appear to be, as expected, negligible. The latter is actually a confirmation of the derived test data integrity.

## Cladding stresses

This research activity was carried out on behalf of Helsinki University of Technology (HUT) under a 3rd party work contract and a full report was issued to the customer. The purpose of this HFR investigation was to scan internal stresses, by neutron diffraction, across the thickness of a ferritic/austenitic steel composite specimen of initial thickness of 150 mm. The specimen was cut to 25 mm at the test location.

Figure 18 shows a photo of the experimental set-up at HFR/HB4 (LCNDF). Additional investigations were carried out in parallel by University of Bristol, HUT and VTT aiming at evaluating these stresses based on deep hole and ring core testing methods and by numerical modelling. A joint paper has been submitted to ECRS-6.

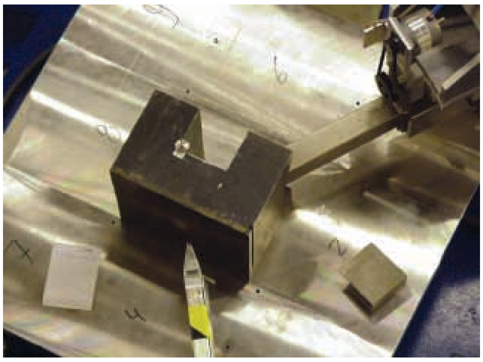


Figure 18: Test set-up for residual stress measurements in the cladding component

**ENPOWER** - Management of Nuclear Plant Operation by Optimising Weld Repairs.

JRC (HFR) is responsible for the evaluation of residual stress, by neutron diffraction, in steel welded specimens simulating repair welds applicable to a range of industrial applications including RPV cladding and primary piping.

## NET related activities

A new Task Group (TG6) has been introduced within the NESC Network with the aim to develop various computational round robins for the evaluation of residual stress in dissimilar metal piping welds. 6 NESC partners, including JRC are committed to performing a number of FEM analyses. TG6 is co-ordinated by JRC (HFR) NET staff, which is also charged with providing reference experimental data, based on neutron diffraction, for the evaluation of the round robins. Figure 19 shows JRC FEM results for an “auxiliary round robin”, which