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Session 1: Irradiation Embrittlement

LYRA and Other Projects on RPV Steel Embrittlement Study and Mitigation of the AMES Network

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ABSTRACT

Within the framework of the European Network AMES, Ageing Materials Evaluation and Studies, a number of experimental works on RPV materials embrittlement are carried out at the Institute for Advanced Materials (IAM) of the Joint Research Centre (JRC) of the European Commission (EC).
The objectives of AMES are mainly the understanding of the property degradation phenomena of RPV western reference steels like JRQ and HSST, eastern RPV steels like 15X2MFA and 15H2X15, and annealing possibilities.
In order to conduct a very high quality irradiation programme, an AMES dedicated irradiation rig, LYRA facility, has been designed and developed at the High Flux Reactor (HFR) Petten.
An other dedicated rig, named LIMA, has been developed at the HFR Petten in order to irradiate RPV steels, internals and in-core materials under typical BWR/PWR conditions. The samples can be irradiated in pressurised water up to 160 bar, 320 °C, and the water chemistry fully controlled.
For irradiation of standard or miniaturised LWR related materials samples, another group of well experienced irradiation devices with inert gas or liquid metals environment are employed. These devices are tailored to their various specific applications.
This paper is intended to give information about the structure and the objectives of the existing European network AMES, and to present the various AMES main and spin-off projects, including a brief description on the modelling activities related to RPV materials embrittlement.

THE ROLE OF JRC-IAM & THE AMES EUROPEAN NETWORKS

The international efforts of the IAEA Working Group on Nuclear Plant Life Management and the OECD Nuclear Energy Agency (NEA) Principal Working Group 3 (PWG3), provide national contacts between institutions working in the field.
Also the IGRDM (International Working Group on Radiation Damage Mechanisms for Pressure Vessel Steel) enables the exchange of information and collaboration for fundamental studies in this area. There remains, however, the problem of developing and maintaining a set of complementary capabilities inside Europe for the mutual

benefit of the Member States. There is also a need in Europe to create a focus for interaction with organisations in the Russian Federation and other countries of Central and Eastern Europe with respect to RPV material condition assessment and annealing.
Although great progress has been made in understanding irradiation and thermal degradation of Reactor Pressure Vessel (RPV) steels, many aspects are still not fully understood (1). In particular the question of the qualification of remedial measures such as annealing and repairs remain where further work is essential.
The Institute for Advanced Materials of the Joint Research Centre (JRC-IAM) plays the role of Operating Agent and Manager of the European Networks ENIQ (European Network for Inspection Qualification), NESC (Network for Evaluating Steel Components) and AMES, each of them dealing with specific aspects of materials behaviour in structural components. The AMES European Network is especially focusing on all the above mentioned ageing/annealing issues.

AMES OBJECTIVES AND MAJOR ACTIVITIES

The AMES network was set up to bring together the organisations in Europe that have the main capabilities on RPV materials assessment and research, with the following objectives:

1. Provide information and understanding on neutron irradiation effects in reactor materials in support of designers, operators, regulators and researchers
2. Establish and execute AMES projects in these subjects areas.
3. Act as European Review Group.
4. Provide technical support to regulatory bodies, General Directorates of the EC and provide a base for development of common European standards.
5. Participation in collaborative programmes with the New Independent States (NIS) and the Central and East European Countries (CEEC)
6. Promotion of: Integration of national programmes
   Validation of techniques
   Definition of European Standards
   Validation and establishment of safe limits for mitigation measures.

The network covers such activities on material studies and expertise as:

1. Review the capabilities within its member organisations together with the existing knowledge base from previous work programmes.
2. Study other components than the Reactor Pressure Vessel e.g. reactor internals.
3. Assess the availability of stocks of irradiated and un-irradiated materials that might be made available for work programmes as well as material that might be recovered from operating or decommissioned reactors.
4. Study model alloys to improve the understanding of the underlying effects for irradiation damage, thermal ageing and annealing.
5. Perform annealing validation and re-irradiation studies on materials of current interest for LWR (Light Water Reactor) systems in Central and Eastern Europe.
6. Develop microstructural models of irradiation damage, thermal ageing and annealing.
7. Study other new materials than the only steels used in the old power plants.
8. Perform studies on irradiation and thermal degradation of materials for a new generation of reactors.
9. Execute a survey of national regulatory requirements and identify existing, planned and required standards at European level relevant to material damage and mitigation methods.

AMES ORGANISATION

The AMES Steering Committee decided to adopt the model of the successful PISC organisation with well targeted terms of reference and project management. The Steering Committee, with an elected chairman, gives guidance to the Operating Agent who appoints a Network Manager and other staff to manage the Network. Specific projects each have a task group to define the technical requirements, liase with the Manager(s), co-ordinate joint activities, and monitor progress. The activities themselves are undertaken by the participating organisations.
The contractual aspects are governed by club-type arrangements between the members (multi-partner collaboration agreement). Participation to the activities of the Network is generally at the member's own expense.
Technical and administrative management of the Network and management of collaborative activities of projects are undertaken by the Operating Agent and Reference Laboratory (JRC-IAM of the EC) as performed in the past for PISC with the effective support or participation of national experts or laboratories as required (2)(3). In particular, the Netherlands Research Foundation (ECN) is in joining JRC-IAM in the AMES Reference Laboratory.
Particular projects, such as the setting up and undertaking of structural tests are sponsored either by individual members or by a common budget or partially through existing EC programmes.
The network started in 1993 and is continually evolving to serve their primary purposes. At some stage consideration, by review, will probably look at the scope in terms of relevance to other branches of industry.
After an initial phase of producing the missing 'State-of-the-Art' reports the main objective of carrying out common projects in the above mentioned field could be developed by detailing three projects of priority. The first of these is the validation of surveillance practice and mitigation methods, which had been split into eight Task Groups. Different projects from these Task Groups are running including modelling activities, others are being developed. Several AMES Reports are at present available, see (4).

AMES MAIN PROJECTS

The Steering Committee has agreed upon the need to develop the following three projects in their order of priority:

AMES 1: Validation of surveillance practice and mitigation methods
AMES 2: Effects of irradiation on reactor internals
AMES 3: Significance of Phosphorus causing low toughness in steels during irradiation

The European Commission, Directorate General XI/C/2 (Safety of Nuclear Installations), has supported the detailing of these projects together with the project chairmen and all AMES members. The projects will be split into individual tasks that are then taken over by members for their completion. Some of the work for the tasks is financed as a contribution in kind; some is carried out by the JRC, the Operating Agent of the Network, and some could be supported by the European Commission, Directorate General XI, XII, I (Tacis, Phare) and others as appropriate in order to reinforce common strategies in the field of pre-harmonisation studies which are relevant to safety related components.

AMES 1: Validation of Surveillance Practice and Mitigation Methods

In the first stage the project AMES 1 had been drawn up in the way it is reflected in the scheme in figure 1. After matching this scheme with interest of the individual institutes the following Task Groups could be established:

Task Group 1A: **Reference Laboratory**
Chairman : L. Debarberis, JRC, NL - L. Tjoa, ECN, NL
Task Group 1B: **Small Specimen**
Chairman : M. Valo, VTT, FIN - E. van Walle, SCK/CEN, B
Task Group 1C: **Property Correlation**
Chairman : C. Bolton, Nuclear Electric, UK
Task Group 1D: **Cladding**
Chairman : K. Gott, SKI, S
Task Group 1E: **Trend Curves**
Chairman : C. English, AEA, UK
Task Group 1F: **Irradiation Conditions**
Chairman : A. Ballesteros, Tecnatom, E
Task Group 1G: **WWER's**
Chairman : J. C. van Duysen, EdF, F
Task Group 1H: **WPS**
Chairman : K. Wallin, VTT, FIN

The responsible officer for the project planning and co-ordination is Ralf Ahlstrand from IVO (FIN) supported by the Reference Laboratory and Operating Agent (JRC Petten).

AMES 2: Effects of Irradiation on Reactor Internals

The second priority from AMES has been given to the project AMES 2 'Effects of Irradiation on Reactor Internals' which is still in an earlier stage.
The objective of the project is to evaluate the issues related to the degradation due to neutron irradiation of the properties of the materials of internal structures of PWR, BWR and WWER. For achieving that three groups of actions have to be considered:

- Collect and analyse information on problems actually observed in operation on internal structures of PWR, BWR and WWER.
- Collect available irradiated materials and data on their properties from actual internal structures or from experiments in test reactors.
- Generate relevant data for an accurate evaluation of the degree of the degradation of the material properties.

During this year it is expected to have a broader picture of other ongoing activities in the field. A study contract was placed by the European Commission (DGXI/C2) to analyse the present situation. It is intended to produce a State-Of-the-Art document describing internals, materials, conditions of operation, problems encountered, review of programmes, available materials, irradiation facilities, conclusions and recommendations for BWRs, PWRs and WWERs.

AMES 3: Significance of Phosphorus in Causing the Low Toughness in Steels

The kick off meeting revealed that there was a need for a project aimed at developing the methodology for both the re-distribution of Phosphorus and the impact of this on mechanical properties. At present there was not sufficient insight to predict when non-hardening embrittlement might be important, and this made it difficult to provide Utilities or Regulators with advice on this phenomena. Since there are also many different nation specific problems in the area it was agreed to firstly find a common approach with the integration of the national activities. A meeting is planned to assemble the necessary information from the national presentations expected.

AMES REFERENCE LABORATORY & LYRA FACILITY

Within the Network a large number of experimental studies on ageing, both thermal and irradiation induced, and annealing are carried out.
Most of the activities are international projects involving several European Member States laboratories and many of the mentioned activities are financed as Shared Cost Actions (SCA) competitive projects by the Nuclear Fission Safety Programme of the EU.
Large parts and tasks of these projects are carried out in Petten by the so called "AMES Reference Laboratory"; a joint effort of IAM and the Netherland Energy Research Foundation (ECN) in order to provide all the necessary facilities and tools required to conduct material ageing studies on both unirradiated and irradiated samples, see (2).
The general objectives of the AMES Reference activities are given in Table 1.
Furthermore, in order to improve the Petten site capability in this field, particular emphasis is given to develop new dedicated unique facilities. Just as unique example, a completely new type of irradiation rig has been developed for the very high demanding AMES requirements and specifications. The new irradiation facility for the HFR, called "LYRA" is a re-loadable, located at the Pool Side Facility, PSF; see figure 2 and 3.
A system of γ-heating shields are designed in order to minimise the thermal gradients and the samples target temperature is maintained by means of a complex system of independently controlled heating plates. The rig temperature range is between 200 to 450 ºC. The required fluence levels typical of RPV end-of-life can be obtained in irradiation time of the orders of 6-8 weeks. A space of up to 59x64 mm is available to accommodate sample holders with different loadings for a maximum length of sample column of up to 350 mm. As many as 140 Charpy V-notched samples (10x10x55 mm) or 10 CT specimens can be loaded. A typical LYRA loading is given in figure 4.
The necessary instrumentation is provided in order to demonstrate the achievement of the irradiation requirements; including sufficient number of thermocouples distributed between the samples, a sufficient number of flux detectors distributed between samples, and one Self Power Neutron Detectors, SPN on the back of the sample holder in order to verify the fluence rate gradients and to be used, after calibration against the flux detectors, as fluence indicator for the following irradiation experiments (5).
Particular effort has been dedicated in neutron spectrum tailoring, by use of 3D MonteCarlo calculations, in order to achieve in the HFR PSF, as far as possible, a typical PWR neutron spectrum, see figure 5.
The list in Table 2 represent a short summary of the most important activities and projects for which an important share of the work is carried out at IAM Petten.

OTHER RELATED JRC-IAM-HFR FACILITIES

Another dedicated reloadable rig, named LIMA, has been developed at the HFR Petten in order to irradiate RPV steels, internals and in-core materials under typical BWR/PWR conditions. The samples can be irradiated in pressurised water up to 160 bar, 320 °C, and the water chemistry fully controlled. A fast (E>0.1 MeV) neutron fluence of ~ 0.5E21 n/cm2 can be reached in one HFR irradiation cycle of 25 days. The available space for samples is an annulus of 32 by 55.5 mm diameter and 360 mm length; an it can be filled up to ~50% of cross-section with samples.
For irradiation of LWR related standard and miniaturised tensile, charpy, CTs and low cycle fatigue samples, a group of well experienced irradiation devices with inert gas or liquid metal environment are available at the HFR. These devices are typically providing an irradiation volume, over three independent channels, of 29 or 31 mm outer diameter for a length of 300 up to 400 mm.
These devices are tailored to their specific applications, see (6) and (7).

MODELLING ACTIVITIES

The demand to assure the RPV-integrity under all conceivable operation conditions is one of the most important safety issues materials scientists have to face. However, a well-founded understanding of materials embrittlement especially of the parts which are exposed to high fluxes of neutron and γ-radiation still presents a challenge for experimentalists and theoreticians. The former have to deliver adequate measures of materials degradation in terms of ductility and microstructural changes caused by irradiation damage; the latter are mainly concerned with the development of appropriate models for residual lifetime predictions in order to avoid unexpected shutdowns or reduced plant life extension margins. Physically based modelling of property changes becomes especially important when embrittlement mitigation methods are applied to extend the plant life. In this case plant specific aspects are important to validate the rejuvenation procedures and the subsequent surveillance practice.

In principle, it is the goal to predict the embrittlement and the fracture properties of structural materials exposed to particle and γ-radiation by characterizing experimentally its microstructural degradation by a combination of advanced techniques such as FEGSTEM , SANS , etc. and its mechanical properties by rather simple tests (tensile testing, hardness measurements, etc.). The outcome of an AMES study contract which should review the theoretical methods which are currently available for modelling irradiation embrittlement are summarised in the following. The non-hardening component to embrittlement, i.e. a loss of ductility without concomitant strengthening of the grain matrix, is associated with the segregation of solute or impurity atoms to the grain boundaries, and acts upon the grain boundary cohesion strength. This type of embrittlement is not yet as well understood as the hardening embrittlement and will not be considered here.

Irradiation-induced degeneration of tensile properties & changes of Microstructure

The microstructural development during fission neutron irradiation depends on the surviving defect structure produced within individual cascades and the subsequent defect migration and interaction outside the cascades. Cascade overlap at higher doses may also play a role. In the operation temperature range of pressure vessels, self-interstitials are mobile and will be trapped by sinks or recombine with vacancies or vacancy clusters. There is experimental evidence that the irradiation-induced microstructural evolution is mainly mediated by the diffusion and interaction of point defects rather than brought about directly by intracascade processes.

For a phenomenological classification of microstructural changes that may influence the mechanical properties one may distinguish three physically different contributions:

a) Matrix Damage

The term 'matrix damage' comprises:

(i) the agglomerates of intrinsic defects (physical imperfections), such as self-interstitial clusters and interstitial-type dislocation loops as well as vacancy-rich regions, micro-voids and vacancy-type dislocation loops and

(ii) mixed agglomerates of solute atoms and intrinsic defects. As regards the complex microstructure of commercial steels, impurity contents are known to play an important role for the growth of matrix defects.

b) Precipitation

A most important contribution to the degradation of mechanical properties stems from irradiation-assisted re-distributions of solute and impurity contents (chemical imperfections). In particular, Cu and Ni have been identified to undergo irradiation-enhanced precipitation from the solid solution of RPV steels. As to the Cu impurities, small coherent body centered cubic (b.c.c.) precipitates are formed that grow up to approximately 4 nm in size without reaching the over-aged stage and that act as efficient dislocation obstacles.

c) Grain Boundary Segregation

While the contributions (a) and (b) give rise to obstacles impeding the motion of dislocations (barrier hardening), irradiation-induced grain boundary segregation of elements like P and S may influence the inter-granular cohesion strength and may therefore act directly on fracture mechanical properties. The corresponding non-hardening embrittlement may then be due to a change in failure mode from trans- to inter-granular fracture which is accompanied by incomplete recovery of fracture mechanical properties after annealing. While the detrimental role of P in causing temper embrittlement of the grain boundaries in ferritic-martensitic steels is well documented little is known about the irradiation conditions promoting irradiation-enhanced segregation.

Strengthening Mechanisms

The strengthening mechanisms, that are relevant for nuclear materials in as much as strengthening efficiency is affected by irradiation, are summarised as follows:

(i) precipitation strengthening,

(ii) strengthening by dislocation loops and

(iii) strengthening by micro-voids. While the strengthening by these mechanisms usually increases during irradiation,

(iv) solid solution strengthening may decrease due to an irradiation induced depletion of solute atoms dispersed in the matrix.

Ductile versus brittle behaviour

A material is said to be ductile if failure occurs by rupture involving considerable plastic deformation and absorption of mechanical energy whereas brittle materials are characterized by a tendency towards low-deformation cleavage fracture. Many technologically important materials, among them ferritic steels used in nuclear reactor pressure vessels, show a ductile to brittle transition.

Theoretical approaches to the DBT-problem comprise different dimensional scales:

(i) the atomistic level (simulations based on molecular dynamics),

(ii) the mesoscopic level dealing with dislocation emission and dynamics in the immediate crack tip vicinity within a single grain and

(iii) the continuum level which, however, should take into account the microstructural heterogeneity due to the grain morphology, precipitations and inclusions etc.

Although the DBT-problem is paramount since many years, there is still no comprehensive and definitive model available and remains "the first fundamental problem of fracture".

Mesoscopic and macroscopic theories are the most promising to be developed for practical applications. With regard to this type of approaches, a twofold duality can be observed. The first one concems static versus dynamic approaches to the DBT problem. This becomes manifest in two aspects:

(i) there are models considering a static crack opposed to models treating moving cracks.

(ii) With respect to the deformation mechanism ahead of the crack tip models looking at equilibrium dislocation arrangements are opposed to models taking into account dislocation dynamics.

In both cases mostly quasi-static approaches are pursued. However, there are also indications that the DBT in materials and loading ranges of practical concern is propagation controlled, in the sense that temperature dependent microstructural

mechanisms allow for the continuous propagation of a running cleavage crack. The second duality is related to statistical versus deterministic modelling.
Statistical models are widely used in engineering approaches to the DBT. They are based on the fact that brittle inclusions (e.g. carbides) may act as fracture initiators. With this type of model based on the weakest-link concept, the scatter of Klc in the transition region, the statistical size effect, and partly also the temperature dependence of the DBT could be successfully described. However, there are also conceptual shortcomings in view of the fact that the DBT is also observed in pure b.c.c.-metals (Fe, Mo, etc.) where no brittle crack initiators exist.
From the above discussion it becomes already clear that a comprehensive understanding of the DBT phenomena has not yet been achieved. It might be well possible that the 'DBT per se' does not exist and that different mechanisms contribute to the phenomenon according to the loading and temperature range, and the specific material under consideration.
The study by Rice and Thomson (1974) can be looked at as a starting point for the investigation into intrinsic mechanisms of the DBT. There a criterion for the possibility of brittle fracture is derived by taking into account the competing mechanisms of spontaneous emission of dislocations from an atomically sharp cleavage crack and of the crack advance by cleavage. If the energy barrier to the formation of a dislocation loop is too high at the point of impending propagation of the crack, brittle behaviour is expected. If, however, this energy barrier is sufficiently low, dislocations will be emitted thus causing crack blunting. In addition, these dislocations shield the crack tip from the external load by reducing the effective crack tip stress intensity.
Therefore two further concepts come into play: crack-tip dislocation emission and dislocation shielding. These concepts have not called the attention from mechanical engineers as much as the statistical models. However, with regard to effects due to thermal ageing and irradiation damage they may play an important role in the future, since the microstructural changes due to these phenomena affect the dimensional scale of elementary deformation and fracture mechanisms.

In general, the deterministic models which take into account the intrinsic plastic deformation mechanisms, mostly based on dislocation behaviour ahead of the crack tip, can be separated into different groups. Most models are dealing with dislocation arrangements in the vicinity of a static crack and only a few are referring to a propagating crack. The static crack models themselves may be subdivided into two groups: those concerned with finding the equilibrium distribution of dislocations ("equilibrium approach") and those which consider moving dislocations in the stress field ahead of a crack taking into account dislocation emission controlled by an appropriate emission criterion ("dislocation dynamical approach"). Also for the dynamic crack models two groups can be distinguished: those describing the plastic deformation around the crack tip by general rate dependent viscoplastic constitutive laws and models taking into account dislocation dynamics ahead of a moving crack.

CONCLUSION

AMES is a well established European network around the subject of irradiation embrittlement and its mitigation methods.

After an initial phase of producing the missing 'State-of-the-Art' reports the main objective of carrying out common projects in the above mentioned field could be developed by detailing three projects of priority.

The first of these is the validation of surveillance practice and mitigation methods, which had been split into eight Task Groups.

At the HFR Petten, the irradiation device LYRA has been developed and tailored in order to conduct the necessary irradiation tasks with the required high degree of accuracy. Other devices are available at the HFR Petten and suited for PWR related irradiation; like the LIMA rig operating at PWR conditions.

Different projects from these Task Groups are running including modelling activities, others are being developed. A problem which encounters the theoretical description of the DBT in commercial steels is the appropriate modelling of the rather complicated microstructure. Nevertheless, progress in the description of phenomena like irradiation embrittlement and ageing on the DBT can only be achieved, if the modelling is formulated on the dimensional scale which is concerned by the damaging processes. The hope to explain the DBT satisfactorily by its influence on easily measurable macroscopic properties (e.g. the flow stress) by the use of a simple macroscopic model has not been granted up to now. Also the statistical models widely used by engineers lead finally to the conclusion that intrinsic mechanisms in single grains are finally controlling the DBT.

There is a close connection between the statistical effects of crack initiation in a brittle particle and the propagation mechanism of a crack running in the first grain i.e. the crack propagation in a single crystal. Once the crack has crossed the particle-ferrite interface, the moving crack tip should start to emit dislocations which interact with the already available dislocation distribution and the crack tip stress. It is then the question whether the microscopic configuration of the lattice defects permit a further propagation of the crack in the cleavage mode. The modelling of this mechanism has already been tackled and it is shown that this should lead to a DBT.

Since also the purely statistical evaluation points to a DBT phenomenon, the combination of both approaches could lead to a better understanding of the complexity of the experimental observations. This necessitates a modelling effort for more relevant load cases from the mesoscopic dislocation approach and an appropriate statistical treatment of a cleavage crack propagating in a ferrite matrix.

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No.2 - State-Of-the-Art review on Thermal Ageing - EUR 16278 EN
No.3 - Irradiation Effects in RPVs; Russian vs. European approaches EUR 16279 EN
No.4 - Survey of National Regulatory requirements - EUR 16305 EN
No.5 - Survey of existing, Planned and Required Standards - EUR 16313 EN
No.6 - A Review of Formulas for Predicting Irradiation Embrittlement of Reactors Vessel Materials EUR 16455 EN
No.7 - AMES Reference Laboratory JRC-IAM/ECN Petten EUR 16409 EN
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AMES Project
Validation of Surveillance practice and mitigation methods

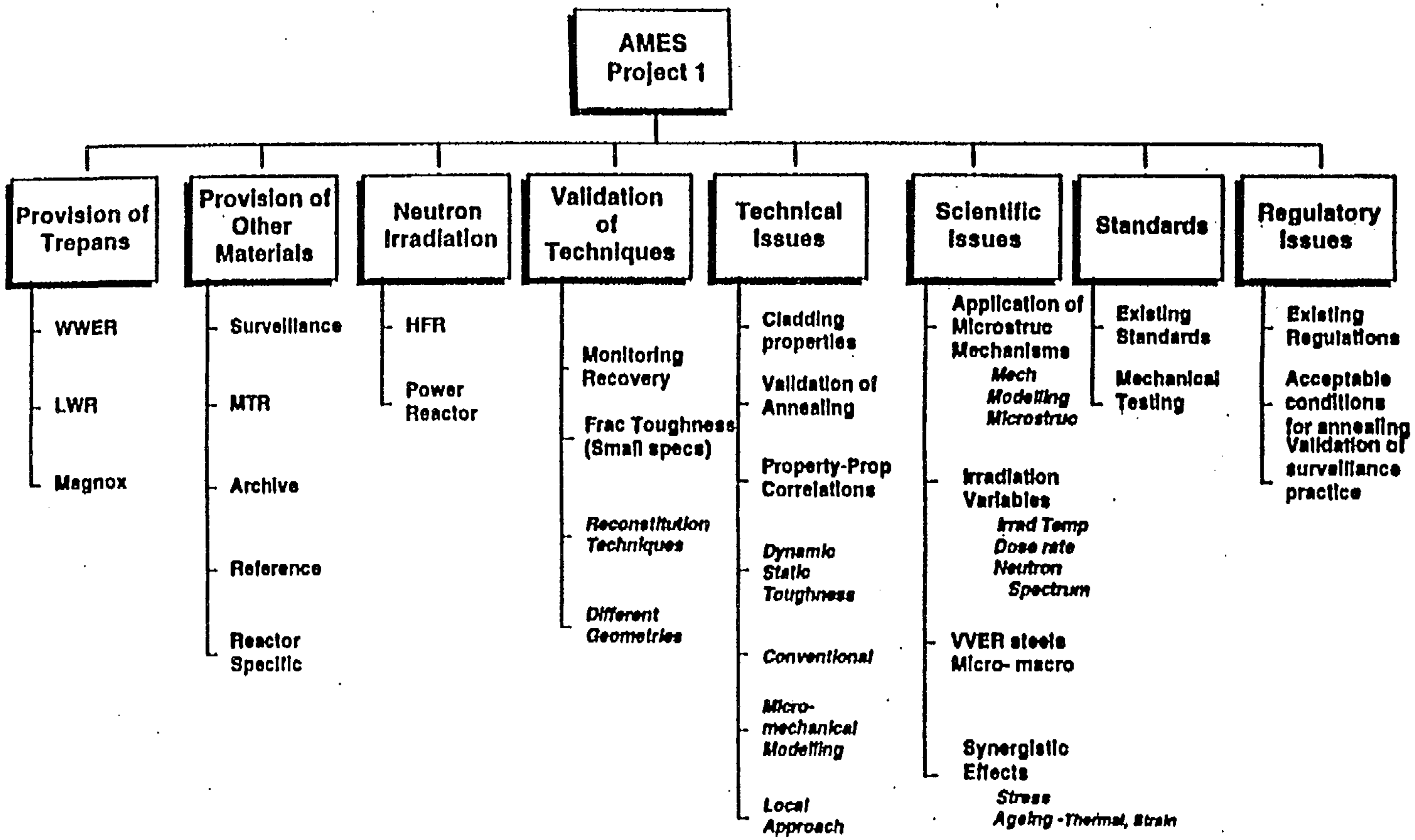

Figure 1: Scheme of the project AMES 1

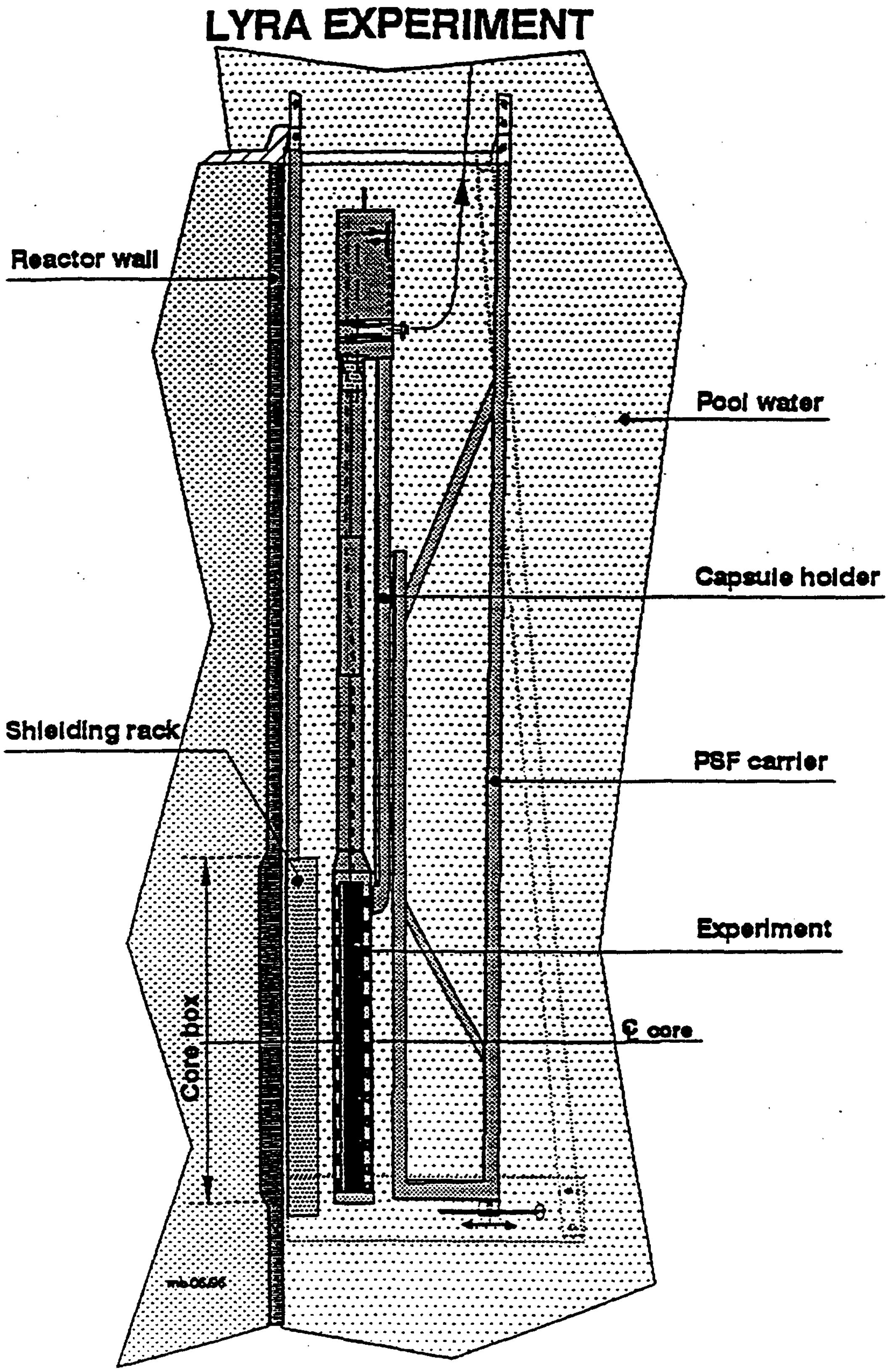

Figure 2. View of the LYRA facility in the PSF of the HFR

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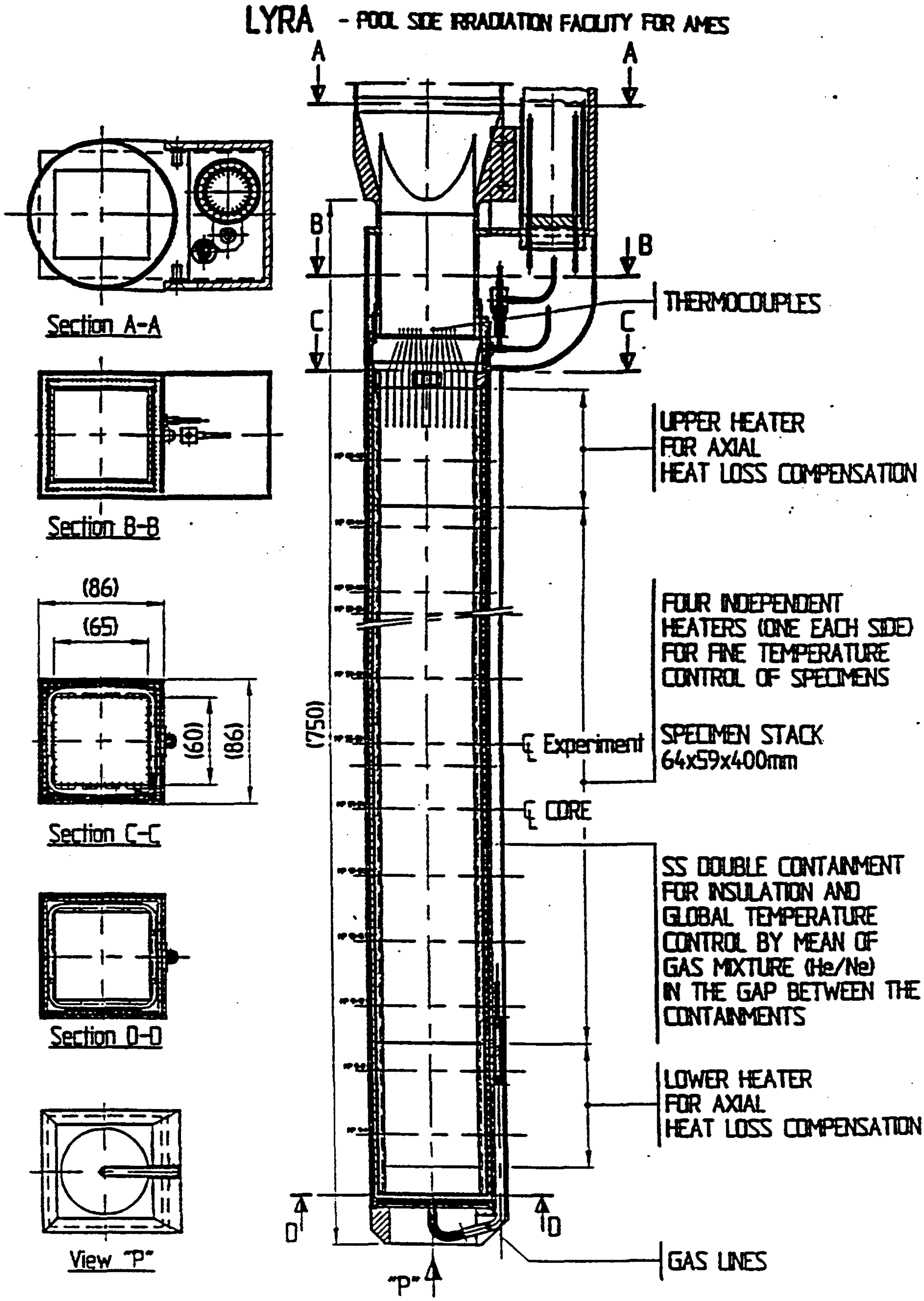

Figure 3. View of the LYRA facility

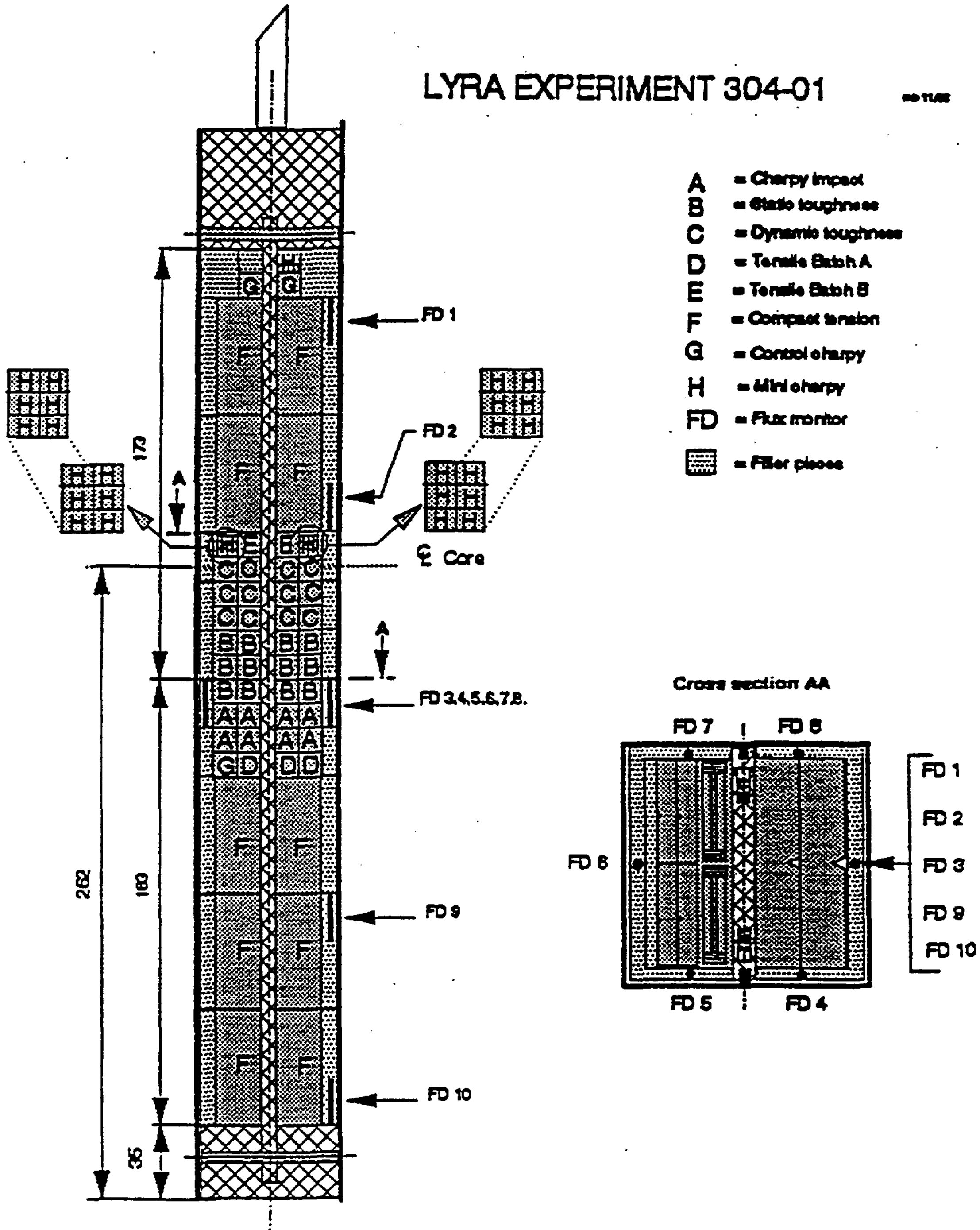

Figure 4. LYRA – Typical sample holder loading

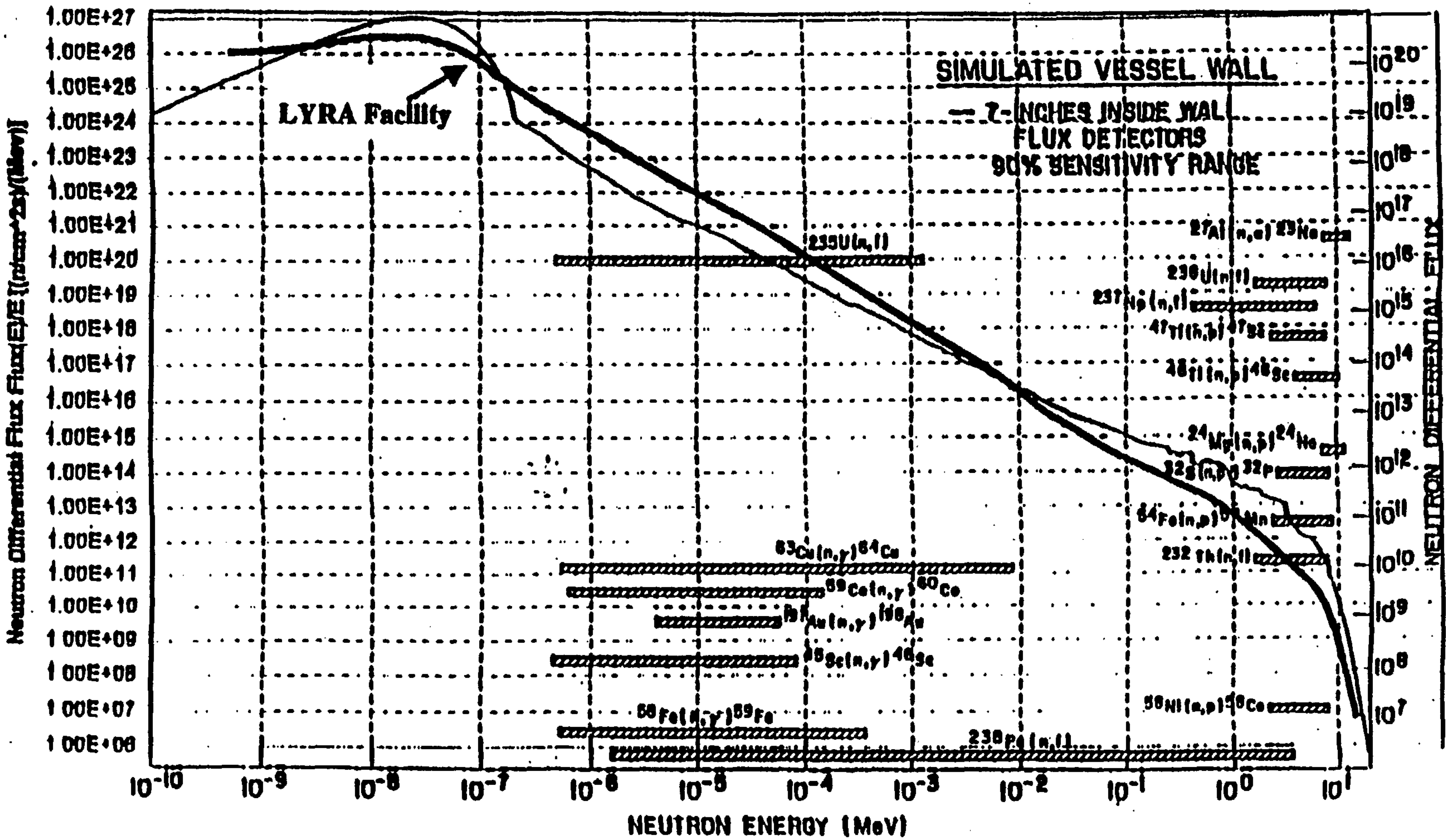

Figure 5. LYRA neutron spectrum tailored to PWR environment

Objectives:	
a)	Carry out experimental study on ageing/annealing • **thermal ageing** • **irradiation embrittlement**
b)	Setting-up develop and maintain: • **thermal ageing laboratory** • **irradiation facility form HFR** • **certified impact testing laboratory, etc.**
c)	Collect Reference Materials • **reference steels (JRQ, HSST etc.)** • **materials coming from aged industrial structures and/or private organisation (GKSS irr.mat.)**
d)	Maintain & develop competence in: • **neutron dosimetry** • **material damage indexation, etc.**

Table 1: General objectives of the AMES Reference Laboratory

Project name	EU contract number	Objectives & **Partners with JRC-IAM**
AMES DOSIMETRY	NFS SCA PL950011	Harmonise dosimetry practices for ageing studies and Establish the dosimetry of AMES activities **Tecnatom, ECN**
REFEREE	NFS SCA PL950073	Assess the correlation between different fracture toughness properties of aged steels; Charpy impact versus dynamic & quasi-static toughness transition shifts measurements **NE, SCK/CEN, VTT**
RESQUE	NFS SCA PL960344	Validation of CV-n sample re-constitution techniques for obtaining more experimental fracture tougness data limiting the amount of material used. Different welding & joining techniques are compared. **SCK/CEN, ECN, VTT, NE, AEA, RCR, Siemens**
SYNTER	NFS TN PL960346	Propose and study safety related innovative nuclear reactor technology elements for present and future type of plants **KFA, CEA, ECN, VTT, ENEA, ENEL, PSI**
MADAM	NFS TN PL960395	Generation of a possible conversion table of material damage indexes for possible comparison of results coming from different test programs and real operating plants **Tecnatom, VTT, NE, ECN, SCK/CEN**
ENUKRA	TACIS PCP III	Embrittlement Assessment of Irradiated Pressure Vessel Steels **Tecnatom, ECN, UNRI**

Table 2: Brief description of the SCA financed projects