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FEUNMARR
Future European Union Needs in MAterial Research Reactors

FINAL SYNTHESIS REPORT

CO-ORDINATOR

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The European Union provides the right international perspective and collaborative spirit for management of the overall European Research Area, and notably in the field of the Material Test Reactor infrastructures.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABWR Advanced Boiling Water Reactor
ADS Accelerator Driven System
AGR Advanced Gas Cooled Reactor
Appm Atoms Part Per Million
AVR Arbeitgemeinschaft Versuchsreaktor / Working Group Experimental Reactor

BNCT Boron Neutron Capture Therapy
BWR Boiling Water Reactor

CAPRA Consommation Accrue de Plutonium dans les Rapides / Accelerated Consumption of Plutonium in Fast Breeders
CEA Commissariat à l'Energie Atomique / Atomic Energy Authority
SCK•CEN Studie Centrum voor Kernenergie / Centre d'Etudes de l'Energie Nucléaire
CERCER Ceramic-Ceramic
CERMET Ceramic-Metal
CFCC Continuous Fibre Ceramic Composites

DOE Department of Energy (USA)
Dpa Displacement per atom

E Energy
EC European Community
EMIR European Network on Nuclear Medicine Applications
EPR European Pressurized Reactor
ERA European Research Area
ERI European Research Infrastructure
ESS European Spallation Source
EU European Union

FBR Fast Breeder Reactor
FGR Fission Gas Release

GT-MHR Gas Turbine – Modular Helium Reactor

HBS High Burn-up Structure
HLW High Level Wastes
HTR High Temperature Reactor

IAEA International Atomic Energy Agency
IASCC Irradiation Assisted Stress Corrosion Cracking
IFBA Integrated Fuel Burnable Absorber
IFMIF International Fusion Materials Irradiation Facility
IRIS International Reactor Innovative and Secure

JHR	Jules Horowitz Reactor
JRC/IAM	Joint Research Centre / Institute for Advanced Materials
LOCA	Loss Of Coolant Accident
LWR	Light Water Reactor
MAGNOX	Magnesium Oxide Gas Cooled Reactor
MeV	Mega-electron-volt
MOX	Mixed Oxide
MTR	Material Test Reactor
MWd/kg	Mega-Watt*day per kilogram (of U or U+Pu)
MWe	Mega-Watt electric
MWth	Mega-Watt thermal
NAA	Neutron Activation Analysis
N/cm^2/s	Neutrons per square centimetre and per second
NEA	Nuclear Energy Agency
NPP	Nuclear Power Plant
NTD	Neutron Transmutation Doping
OECD	Organisation for Economic Co-operation and Development
PBMR	Peeble Bed Modular Reactor
PCMI	Pellet Cladding Mechanical Interaction
PET	Positron Emission Tomography
PLEM	Plant Life Extension and Management
PWR	Pressurized Water Reactor
RBMK	Reaktor Bolchoï Mochtchnosti Kanalni / Russian Boiling Water Reactor - Graphite moderator
RIA	Reactivity Insertion Accident
R&D	Research and Development
RR	Research Reactor
TA	Technicatome (France)
TN	Thematic Network
UJV	Ustav Jaderneho Vyzkumu
UK	United Kingdom
USA	United States of America
VVER	Vodanio Vodanoi Energuietitcheski Reaktor / Pressurized Water Power Reactor

EXECUTIVE SUMMARY

The European Atomic Energy Community agreed a project[1] in the frame of the 5th FP, named FEUNMARR, with the French Commissariat à l'Energie Atomique to investigate the future EU needs for Material Test Reactors (MTRs). Discussions among the FEUNMARR project members pointed out the following main outcome :

- There will be a need for MTR experimental capabilities as long as nuclear power retains a significant share in the mix of energy production sources. Considering that the nuclear option will continue to be available at least for the next several decades, it is important that the technical infrastructure and support provided by MTRs remains accessible on the long term.
- For current generation reactors, MTRs represent an invaluable resource to assess new materials, to explore modified operational conditions and to address design basis safety and unanticipated operational issues that can develop. History shows that the latter are not uncommon even for mature systems. Another area of interest relates to plant life extension.
- For new generation reactors, MTRs will be needed both for on-going support to evolutionary designs (Generation III and III+) and for more fundamental assessments of more innovative designs (Generation IV). MTRs will have a central function for specific issues and qualification process imposed by these designs.
- Moreover, MTRs will be used also for nuclear fusion and spallation reactor technology. Some of these future systems will require high energy neutron flux. Recent years have also seen the growth in nuclear medicine and allied medical applications, and silicon neutron doping, all requiring a source of neutrons. This area should be considered as a very important complement to MTR test activities for the nuclear power industry.
- Materials test reactors should form the basis for an infrastructure aimed at producing expertise and retaining competence in nuclear science and technology, where international exchange of experience is a key factor. Such an infrastructure may also be part of the technical basis for the decision-making process on nuclear energy matters in Europe.

European MTRs are ageing and measures should be put into effect to secure a reasonable degree of continuity for when the existing European MTRs will cease to be in service. While it is difficult to provide firm timetables on developments that will take place in several years and that will depend on a variety of conditions, the FEUNMARR project members believe that at least one new European MTR should be in operation in about a decade from now. Considering the time needed for constructing and achieving steady operational conditions, the above conclusions mean that a decision in principle on the construction of a new MTR facility must be taken in the very near future. A new MTR facility should be seen in the context of the overall European research infrastructure and it is in this sense that the EU can provide the vision and depth needed for such an initiative to be a success.

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[1] Contract No FIR1-CT-2001-20122

1. OBJECTIVES ANS SCOPE OF THE WORK

1.1 Background

European research reactors have provided essential support for nuclear power programs over the last 30 years or more. More recently, as a source of energetic neutrons, they have also become an important service provider to the medical fraternity and isotope industry. However, by 2010 most of the Material Test Reactors (MTRs) will be at least 40 years old and many will require license renewal to remain operational, with some facing potential closure. In order to address the implications raised by the potential loss of several MTR facilities and associated services after 2010, the European Atomic Energy Community agreed to a project with the French Commissariat à l'Energie Atomique named FEUNMARR, to investigate the "Future EU Needs in Material Research Reactors".

The contract for this 'thematic network' study was signed on 19 October 2001 and takes place within the fifth Framework Programme 1998 – 2002. This final synthesis report contains the findings, conclusions and recommendations of the group of contracting partners (the 'group') who have participated in the project.

1.2 Project Objectives

The principal objectives for the work to be carried out in the FEUNMARR project are:

- To determine and make recommendations on the future irradiation needs for MTR facilities in Europe capable of carrying out experimental and safety programmes to support the continuation and further development of commercial nuclear energy.
- To determine the most likely types of problems, measurements and examinations that will form the basis of the anticipated experimental and safety programmes.

Some MTRs also provide the facilities and irradiation conditions for branches of nuclear medicine, basic research and other industrial applications requiring neutron sources. These supporting MTR needs are also defined as part of this project.

The group recognises that its recommendations will contribute to the policy for an associated European Research Infrastructure (ERI) whose aims are currently being considered within the sixth Framework Programme.

1.3 Scope of the Work

The group has defined project timescales and two areas of review outlined below. The project timescales are short term (present – 2007), medium term (2007 – 2012) and long term (beyond 2012). The review areas are:

a) The current status of:

- European MTRs
- Commercial nuclear power programmes and future projections
- Utilization of MTRs for medical purposes
- Other applications requiring MTRs as a source of neutrons

The above area comprises section 2 of this summary report.

b) The future experimental, testing and industrial needs for MTRs in the short, medium and long term in the areas of:

- Nuclear fuels, materials, coolant interactions, safety and treatment of spent fuel and residues for current and future power reactor systems
- Neutron beams for medical applications and research
- Other uses requiring neutrons, including the treatment of waste and isotope production

This area is covered in sections 3-5 and is the main focus of the project. It contains the views of the project group, who have also drawn on the contributions from expert invited to the Cadarache Workshop held during 27 February –1st March 2002. The detailed MTR needs in the main technical areas are described in Chapter 3. The main MTR specifications, operational framework and experimental tools required are discussed in Chapter 4. The overall conclusions and recommendations from the project are provided in Chapter 5. *Conclusions* are drawn on MTR needs in Europe relative to anticipated demands (i.e., the future of nuclear power, medical requirements and other uses, etc.). *Recommendations* are then formulated to provide guidance on:

- How to meet the identified needs in terms of availability of MTR facilities and services, including supporting scientific and technical infrastructures
- How to structure a possible future network of competence throughout the European Community in support of a fission energy production industry.

2. CURRENT STATUS OF TEST REACTORS AND PROGRAMMES

2.1 European Materials Test and Research Reactors

In Europe at the present time there are several operating research reactors with a power of at least 10 MWth that have the capability for material and/or fuel irradiation testing. Amongst these are BR2 (Mol), HFR (Petten), LVR15 (Řež), Halden Boiling Water Reactor (Halden), Osiris (Saclay) and R2 (Studsvik), and up to ~2010 these MTRs are likely to satisfy all current European needs (as well as many international) for neutron irradiation. However, by that time all of these reactors will be approaching or over 50 years of age and will all potentially be nearing the end of their operational life. Although it is likely that some applications will be made for continuation of operation beyond their anticipated lifetime, it is not at all certain that these will be granted, or would be cost-effective if plant improvements were required. It should also be noted that the risk of closure of some facilities on political and/or environmental grounds is at least as great as that due to age considerations.

Experience feedback shows that all of the MTRs aged over 50 years and a large number (more than 50%) of the test reactors aged 40-50 have been shutdown permanently. This means that historically the lifetime of an MTR has generally been up to 40-50 years. So currently operating European MTRs are approaching an age, which, from past experience, can be considered as their maximum expected lifetime.

All of the current MTRs have a variety of technical capabilities such as in-core instrumentation and controlled experimental conditions together with sufficient flexibility to cover a wide range of technical needs. In addition to nuclear power industry requirements, European MTR's have been able to satisfy the increasing demands of the radio-pharmaceutical, medical and other industrial applications. Similar services exist in other parts of the world, but for strategic and economic reasons there is a continuing need for MTR facilities in Europe. The necessity for higher fast neutron fluxes in MTRs is also foreseen. Two proposals whose designs are relatively well advanced are CEA's Jules Horowitz Reactor (JHR) and SCK•CEN's MYRRHA facility.

In addition to satisfying irradiation and research needs, MTR facilities have historically provided valuable education and training support to universities offering courses in nuclear engineering and allied subjects. If nuclear power production is to continue in Europe, there is a clear need to maintain staff competence for the industry at large. An MTR-associated "Centre of Excellence" that provides education and training could cover a central role for certain MTRs, given the urgent and growing need for nuclear power expertise as the present, aging teams retire.

2.2 Commercial Nuclear Power Production

Commercial power reactors for electricity production operate in more than half of the countries comprising the EC and include a range of different designs (AGR, BWR, MAGNOX, PWR, and VVER). The majority of these Generation II plants are reaching the end of their design life (~30 years) but it is anticipated that some operators will acquire licenses to extend lifetimes up to 60 years. In many respects the reliable and safe performance of the current fleet of reactors is based on large research programmes carried out earlier, largely in MTRs and post-irradiation facilities.

At present, on a world-scale, there are increasing signs of a revival of nuclear energy brought about by several factors. Although plant lifetime extension and management (PLEM) programmes may delay the introduction of Generation III reactors, designs are well-advanced for the European PWR (EPR), the ABWR and the high temperature reactor (HTR) as well as alternative international designs that may supersede the present light water and graphite-moderated plants currently in operation in the EC.

Generation IV reactor designs, such as the gas-cooled fast reactor and others, are under discussion as a way of addressing the question of global sustainability. They also open the way for improvements in the management of nuclear materials to make them proliferation-resistant. In this regard Generation IV designs are characterized by long operating cycles (> 4 years) so that the containment vessel is opened infrequently. The latter has implications for new types of fuel assembly materials and the MTR testing that will be required to qualify them.

2.3 Nuclear Medicine

There has been a strong and steady growth over the last ~10 years in the demand for neutron sources for clinical uses in nuclear medicine. This service to the community requires coordinated planning between reactors with similar and compatible functions. The direct use of collimated fast and soft neutron beams for cancer therapy is also increasing (e.g. BNCT).

In the short-medium timeframe (to 2012), all European and some international needs are likely to be adequately met by existing operating MTR facilities. These are principally HFR (Petten), BR2 (Mol) and OSIRIS (Saclay); FRJ2 (Jűlich) has also recently commenced irradiations. Beam tubes for research into neutron capture therapy are available in HFR, R2 (Studsvik), LVR15 (Řež), TRIGA (Finland) and shortly in FRM2 (Münich).

2.4 Basic Research and Other Techniques and Applications Requiring Neutrons

Basic research in fields such as radiation effects on materials, radio-chemistry and radiolysis require neutron sources. Also, several powerful analytical techniques require fission-generated neutrons for their application (neutron radiography, neutron activation analysis, gamma-ray irradiation of various materials and of food and medical equipments for sterilisation).

Other industrial applications for MTRs include the production of radioisotopes for the non-destructive testing of welds by γ-radiography and of Neutron Transmutation Doping (NTD)-silicon for the electronics and heavy electrical engineering industries.

3. CURRENT AND FUTURE RESEARCH AND DEVELOPMENT REQUIREMENTS

3.1 Background

This section considers the need for MTRs in the future to support principally the nuclear industry, but also the provision of facilities for nuclear medicine and fundamental research studies. In addition, the case is made for such facilities to provide in parallel, high quality education and practical training of future engineers, technicians and scientists.

The requirement for future research into nuclear fuels and the provision of MTR facilities is conditional on a number of issues. First and foremost is the fate of the nuclear industry and the public acceptance for producing part of future energy demands by nuclear reactors. The next question is whether or not future reactors will deviate significantly from the current LWR designs. This question is important, as it has an impact on the amount of R&D required to support the nuclear programme.

For any particular reactor design, R&D requirements can be grouped into two main categories. The first can be referred to as ‘start-up’ R&D in order to qualify both the reactor design and the materials to be used. This work has to be performed in advance of commercial operation. The requirement for this category reduces with time as the design reaches maturity. The second is ‘on-going support’ which, as it’s name suggests, accompanies commercial operation up to the end of reactor life. The purpose of this is for developing new materials, qualifying new modes of operation and for addressing unanticipated issues as they occur. History tells us that the latter occur regularly even for mature systems.

3.2 R&D Requirements for Generation II Reactors

The current generation of LWRs have operated very successfully for over 30 years, and with plant lifetime extension programmes (PLEX), individual reactors are expected to have a lifetime approaching 60 years, i.e., up to the year 2030. Much of the start-up R&D has been completed, although safety issues appropriate to high burn-up are still being addressed. In general, for these reactors, R&D has already entered the on-going support phase. The main topics of current concern are as follows:

- *High Burn-up Behaviour*, which involves R&D into new cladding materials to minimize waterside corrosion. Regarding the fuel, two issues are constituted by the rod over-pressure due to the high inventory of fission gases, and the mechanical properties related to Reactivity Insertion Accident (RIA) or Loss of Coolant Accident (LOCA).
- *Plant Lifetime Extension (PLEX),* which needs on-going surveillance programmes in MTRs related to the pressure vessel and structural components and their embrittlement with irradiation by fast neutrons.
- *Introduction of MOX,* for which current studies are mainly concerned with high burn-up issues in order to establish parity with UO_2 fuel operation. The database for MOX is less extensive than for UO_2 and developments in microstructure are still being pursued by new manufacturing methods. For these reasons, there is an ongoing requirement for basic R&D on MOX fuel including MTR irradiation under off-normal conditions.

3.3 R&D Requirements for Generation III & III+ Reactors

Apart from the Pebble Bed Modular Reactor (PBMR), reactors of this generation are developments of the current design Generation II. In all current designs, the conditions of fast flux and power density are lower than for Generation II reactors. One characteristic is the introduction of passive safety features that should make them intrinsically safer. Most of the start-up R&D should already be covered by the existing experience database. R&D including MTR requirements are mostly confined to on-going support, including the facility to address unanticipated problems as they occur. However, it is clear that there is a significant amount of R&D and materials qualification required. For the introduction of HTR systems to commercial operation by 2010 as suggested, it is envisaged that MTR testing will be required in both short and long term.

3.4 R&D Requirements for Generation IV Reactors

These designs incorporate many innovative features including: passive safety, high thermodynamic efficiency, proliferation resistant fuel and can be built in a series of modules. These advantages provoke a great incentive for commercial development of these systems. They encompass a wide variety of designs including reduced moderator LWRs, HTRs and liquid metal cooled reactors. The HTR and liquid metal cooled designs are likely to suffer from the ’knowledge gap’ in the same way as the PBMR and therefore will require extensive R&D and MTR irradiation for materials development and qualification. Material compatibility will become more of an issue because of the more onerous conditions of fast flux, temperature and burn-up. In particular, the high flux and high temperatures of advanced LWR concepts moves coolant chemistry into a regime completely outside current experience.

In this case, there will be a significant effort required to quantify the new reactions and active species generated under these new conditions.

3.5 Generic R&D for the Fuel and Fuel Cycle

Independent of reactor system, there is always scope for new materials and new fuels. The employment of such radically different materials could only take place after extensive testing under a variety of normal and off-normal conditions. One of the major problems with oxide fuels is their poor thermal conductivity. Improvements in conductivity have been tried using Cermet and Cercer matrices, and inert matrix fuel is another form currently being investigated and irradiation programmes are at an early stage. Within this class of fuel material comes the proliferation resistant "rock-like" ROX fuel, so called because of its resistance to dissolution in nitric acid.

Finally there is thorium fuel. The use of thorium-based fuel cycles has been studied for about 30 years, but on a much smaller scale than uranium or uranium/plutonium cycles. Its potential for breeding fuel without the need for fast-neutron reactors holds considerable potential long-term. It is a key factor in the sustainability of nuclear energy. Use of the thoria cycle therefore would require long term R&D and MTR irradiation facilities in order for it to match the licensing requirements for the uranium/plutonium cycle.

3.6 R&D Requirements on Plutonium Management and Nuclear Waste

One of the major problems of nuclear energy is now the management of nuclear wastes and the plutonium stockpile minimization. These two topics require studies in research reactors focusing on: transmutation of actinides and plutonium utilization, new systems dedicated to waste minimization and waste burning, decreasing the amount and the toxicity level of wastes.

3.7 Irradiation Needs for Accelerator Driven Systems (ADS) Development

Presently in Europe two main concepts are considered for the ADS development: a Pb-Bi cooled and a gas cooled system. Whatever is the final choice, studies will be necessary to cover the qualification of the coolant, the spallation source and the materials submitted to higher levels of fluence than that experienced in the current generation reactors.

3.8 Irradiation Needs for Breeding Blanket and Materials in Fusion Research Programmes

The long term development towards fusion power plants aims for materials which can withstand high neutron wall loading and heat fluxes and coolant pressure conditions at temperature attractive for efficient thermodynamic working cycles. In addition the materials should be compatible with high neutron fluences in a power reactor to limit the necessary replacement of the in vessel components to a minimum and should be of "low-activation" type to maintain one of the most attractive features of fusion. It is recognized that the special testing requirements of the fusion program using high energy neutrons for *torus* components could also be partially met by an MTR.

3.9 Education and Training

Over the past 20 years, the number of institutions and universities offering training in nuclear engineering and reactor operation has declined markedly. With a continuing programme of nuclear generation, there is a clear need to maintain staff competence by a concomitant education support to the industry. The establishment of Centres of Excellence surrounding the operation of future MTR facilities and the provision of education and training would provide an additional reason to support future MTR operation.

3.10 Nuclear Medicine

Nuclear medicine alone is covering about 10 million medical procedures per year in Europe and 15 million in-vitro analyses. It is a market in global expansion, with much research and rapid evolution. Because of the importance of nuclear medicine and of the short lived ^{99m}Tc used in the majority of applications, there is a need to safeguard a long term operation of at least three European co-ordinated reactors. Such is the role of EMIR which is a network dedicated to the provision of services in the field of nuclear medicine.

3.11 Fundamental Research and Industrial Applications

Research reactors have also a use in radioisotope production and neutron beam analysis for a wider range of clients. The main use for radioisotopes is for measuring wear, the production of sealed sources for measuring and inspecting welds and the sterilization of food and medical equipments. A further use of irradiation facilities is the use of neutron irradiation for silicon doping. This is performed on an industrial scale and forms a significant source of income for MTR operators. It is envisaged that requirements for this service will continue in future years.

4. MATERIALS TEST REACTORS : OPERATING FRAMEWORK

4.1 Background

With the current generation of nuclear power plants approaching maturity, the research conducted in material test reactors has gradually concentrated on issues related to improved operational economics, safety and reliability. In particular, nuclear operators have made operational changes and introduced measures to enhance safety, fuel utilisation and to extend the lifetime of nuclear power plants. These initiatives have required and are still requiring specialised research, including experimental verifications and data from MTR simulations. At the same time, a certain rebirth of the industry is giving rise to new reactor concepts, which are likely to require radically different technologies, as well as verification and testing in MTRs. A few reactors appear to have been successful in this difficult market, these being BR2 in Belgium, LVR15 in the Czech Republic, R2 in Sweden, HFR in the Netherlands, Siloé and Osiris in France and the Halden reactor in Norway.

4.2 Basis for Development of Programmes

4.2.1 The Reactor

The reactor design and the ancillary infrastructure must be tailored to the purpose of the intended programmes. However, it is very difficult to predict decades ahead what the utilisation of a test reactor will be. Flexibility and ability to adapt to changing market needs will thus be essential for success.

MTRs are normally capable of performing a variety of test irradiations at the same time, thus sharing the cost of reactor operation among many users. How many concomitant irradiations can be done depends on a number of factors related to the test reactor design as well as to the nature of the test irradiations. The Halden reactor can host typically 30-35 tests running at the same time.

For MTRs, the driver fuel acquisition and disposal constitutes a very important item. Due to the high enrichment and special geometry, there are normally very few potential suppliers. This, together with the fact that the market is rather small, makes the MTR fuel very expensive (and its procurement uncertain).

4.2.2 Associated Technologies and Facilities.

Test rig design and fabrication

Test reactors must be able to adapt to a variety of demands and to provide tailor-made solutions that can best respond to the test objectives. Having own workshop facilities with design and fabrication capability is the best way for test reactors to address this requirement, in particular for keeping control on costs and quality. Such design and engineering facilities can also fulfil an important role in the area of education and training.

In-reactor instrumentation

The value of in-reactor experiments increases dramatically if adequate instrumentation is employed to measure relevant parameters on-line. Firstly, in-reactor instruments provide a monitoring of what the test conditions are. Secondly, they provide performance data during actual operation, which are very important for both safety and reliability assessments. Thirdly, instruments enable a cross-correlation of different parameters.

Loops and coolant control

Simulations of reactor conditions require the use of loops where the coolant is circulated at prototypical temperatures and pressures. In addition, it must be ensured that the coolant chemistry is maintained within very precise specifications. The ability to control thermal-hydraulic and chemistry conditions is essential for the success of loop tests.

Hot cells

All European MTRs have associated ancillary facilities and hot cells, which are in most cases located at the same site This situation facilitates the technical integration, and is a vital question when considering ways to minimise radioactive transports across Europe. Such transports are becoming a major cost and licensing item.

Re-fabrication techniques

Experiments in the fuel and materials area must be made with specimens that are fully representative for reactor materials. To this end, the capability to fabricate test specimens starting from radioactive fuel or materials discharged from a power plant is needed. This technique, which is essential for research in support of operation of existing plants, can only be implemented in hot cells.

4.2.3 Management Issues

Combining uses

Experience shows that test reactors can fulfil different tasks, such as for instance performing tests for nuclear power development concurrently with production of radioisotopes for medical applications. In Europe, status differ considerably from reactor to reactor, depending on a variety of conditions that can change from case to case and that can evolve with time. It is advisable, however, that a test reactor has a well-defined focus and mission, and that this is well understood both by the staff within the organisation and by the outside world.

International collaboration

Most of the European MTRs were constructed to fulfil a national mission, at a time when nuclear received considerable government attention and funding worldwide. Since then, the situation has changed considerably and today most test reactors have to rely on diverse sources of funding, i.e. from industry, regulators and governments. One way to achieve international support is by means of international projects, that is projects that are able to combine the interests of many participants and that are financed through cost-sharing arrangements among such participants. Having a strong international dimension will be a decisive factor for the success of any new MTR initiatives.

International networking

Experience shows that more than one test reactor is needed to cover even the irradiations needed in the nuclear fuel and materials area alone. Each MTR has its own special features and capabilities and customers may prefer one or another test reactor depending on schedule or on technical and financial conditions that are offered. It is possible that for the future, European MTRs could constitute a common platform, where - in responding to customer demands - the speciality of each reactor could be utilised in an optimal way.

Training and education

The role of MTRs on education and training must be considerably strengthened in the future. One of the most successful means of staff training is the secondment of personnel from utilities, vendors, licensing authorities and universities, guiding towards a practical outcome in the field of management and planning of MTR operation, and design and execution of irradiation experiments.

4.3 Issues of Importance for Future MTRs

In establishing the design and the operational criteria and guidelines for future MTRs it is important to utilise the wealth of experience accumulated through operation of current MTRs in the best possible way. The design of a new MTR should aim to incorporate the best features of all European MTRs presently in operation, especially regarding:

- thermal and fast neutron flux
- number and size of irradiation position available
- loop capability
- type of driver fuel
- surrounding infrastructure such as hot cells or other nuclear test facilities
- capability of commercial productions for medical and industrial applications
- function of education and training

It is recognised that careful considerations are to be made with respect to issues such as flexibility, especially with regards to dedicated or multipurpose use of the reactor. In the short term, possible constraints can be overcome by networking with existing MTRs. Experience in managing international programmes is also an essential quality for establishing stable business relations for any MTR.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Status and Evolution for Power Reactor Applications

Five materials test reactors cover most of the current irradiation needs in Europe. They are the Swedish R2 in Studsvik, the Belgian BR2 in Mol, the European HFR in Petten, the Netherlands, the French OSIRIS in Saclay and the Norwegian HBWR in Halden.

Europe will strongly rely on the availability of technical and scientific infrastructure to continue providing the basis for the renewal of its nuclear electricity supply capability in the medium and long term. Considering that current European MTRs are ageing, the FEUNMARR project members believe that the need will arise for new MTRs in Europe. In particular, one new MTR should be in place in about a decade from now. The CEA propose to build the JHR reactor at the Cadarache site as an international initiative, with the intent to provide an effective tool that can help addressing needs of the nuclear international community in the medium and long term. As the implementation of a second generation MTR requires one decade, decisions on the construction of such test reactor must be taken now.

Following the example of for instance the OECD Halden Reactor Project structure, a new MTR should be operated as an user-oriented facility providing worldwide services and international R&D programmes for industry, regulators and R&D centres.

It is worth noting that a new single, high capacity facility, when suitably combined with other MTRs and test facilities, would be able to fulfil most of the European needs for many decades. However a single facility would be vulnerable to technical hold-ups such as routine or abnormal shutdowns. The availability of more than one facility also provides scope for competition to ensure economic irradiation services. For the coming decades, securing the required irradiation capability in Europe can be performed in an effective way by networking a new reactor like the JHR with existing test reactors.

5.2 Status and Possible Evolution for Medical Applications

The production of irradiations for medical isotopes and applied medical purposes for Europe is mainly (and adequately) covered by the Petten centre, and to a lesser extent by the other European reactors. Because of the short life of most medical isotopes, delay between production and use has to be shortened as much as possible. Therefore an effective network of competence has been built among the European producers of medical services, in order to assure continuity of service also when a reactor is shut down for maintenance or for other reasons.

A continuous and growing need for nuclear medicine exists in order to have reliable capabilities to provide medical nuclear products, diagnoses or treatment facilities at the reactor site. Because this field is strategic within the European society health policy, it is considered as a relevant option to implement in Europe a dedicated reactor for medical application. Because of strong economical competition in that field, the design will be specific to this application. However, to provide back-up capability, linking of several research reactors is required.

5.3 Status and Possible Evolution for Basic Research Applications and Other Techniques Requiring Neutrons

Regarding basic research there is already a high level modern capability in the ERA so that the relevance of new proposals has to be carefully investigated from the cost and benefit points of view.The production of isotopes, silicon doping as well as other applications, such as activation analysis or neutron-radiography, are considered as a side-application of neutron sources. Up to now these needs have been adequately met by existing reactors.

5.4 Development of Accelerator Driven Systems (ADS)

A political demand exists in a few countries to investigate transmutation as a contribution to waste management. A specific process consists of coupling an accelerator and a reactor. This quite new system still requires a whole set of studies that make necessary to implement a dedicated demonstrator. Such a demonstrator is by itself a topic of R&D.

Both the analysis of the cost-benefit of ADS systems for the waste management and the specification of a relevant demonstrator are important tasks to be broadly shared in the European Community. This can be performed within the successive Framework programs and is not considered further here at present.

SCK•CEN volunteers to study and build a specific facility, called MYRRHA, with programme objectives to assess the transmutation process and the irradiation of materials under appropriate conditions, for ADS and other systems requiring fast neutrons.

5.5 Recommendations

The recommendations of the FEUNMARR group are as follows:

- Given the age of current MTRs, and anticipating continued R&D demand in the 21st century for material and fuel tests in support of nuclear energy production, there is a strategic need to renew material test reactors in Europe.

- Considering the lead-time before a new system can become operational, a decision to build a first new MTR in Europe is required in the very near future.

- The initiative to build the Jules Horowitz Reactor (JHR), and to organise an international programme around it, is an important contribution to the joint development of a new European Material Test Reactor.

- A new MTR, such as the proposed JHR, should in due time establish robust technical links with existing MTRs, aiming to provide a broad and efficient network of facilities at service of the international nuclear community. Programmes should be devised to reach a worldwide range of customers.

- A new MTR should support education and training for future teams of nuclear scientists and engineers, and help providing the European member states with the expertise that will be needed in areas such as nuclear reactor engineering and plant safety.

- There is an increasing reliance by the medical and pharmaceutical professions on research reactors to produce radioactive isotopes. Co-operation between at least three reactor sites within Europe is required in order to ensure a stable supply. If there is a risk that stability of supply cannot be ensured, the building of a new dedicated facility should be considered.