# IAEA RECENT ACTIVITIES TO CREATE A DATABASE ON ASSESSMENT, MONITORING AND SURVEILLANCE OF RESEARCH REACTOR'S CORE STRUCTURAL MATERIALS AGEING

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## ABSTRACT

Following the international crisis due a severe shortage of Mo-99 and the increasing concern regarding the ageing RRs, the IAEA launched a multiannual on-going programme to create an international Database on Assessment, Monitoring and Surveillance on ageing of core structure components materials, recognizing that archived data is unavailable for the Member States (MS). The paper presents the details of this programme, including an overview of the content and conclusions of past activities, as well as near future projected endeavours. The first recent activity was a Consultancy meeting (CS) conducted in INL (USA) on June 2009, with the topic of *Assessment of Core Structural Materials Surveillance Programme of RRs.* That meeting was followed by a Technical Meeting (TM), with the identical title, hosted by the Agency on June 2010. Following the TM a TECDOC publication was prepared, including and analysing nineteen (19) contributed papers. Then after, upon the recommendation of the TM, a second CS will be organized on October 2011, with the topic of *Integrity Assessment of Research Reactor Core Components for Lifetime Extensions: Process, Status and Future perspective.* This meeting will determine the scope and format of a multi-annual Coordinated Research Programme (CRP), including recommendations for the methodology and Database concept to the assessment of RR core structural materials for lifetime evaluation and extension. Furthermore, it is expected from the experts to identify key MS contributors to the CRP on the same topic, to be initiated in 2012.

## INTRODUCTION

Today, about 60% of operating Research Reactors (RRs) are over 40 yrs. old, and their continued running has to be pursued with an ageing management programme. Ageing management is defined as engineering, operation and maintenance strategy and actions to control, within acceptable limits, ageing degradation of structures, systems and components (SSCs) important to the safety [1]. The most challenging activity in the ageing management programme is to continuously review the core structural materials condition, due radiation induced (RI) and corrosion induced (CI) damages, upon the IAEA Safety Standards recommendations [1], [2], [3].

In August 2008, the HFR-Petten (Nl) RR was stopped due a gas leak discovered during a routine check which evolves to a major refurbishing process of the corroded tank base in the primary circuit, disabling medical isotopes production for many months. A couple of months later, on December 2008, AECL decided to shut down the NRU RR, following a heavy water leak and release of tritium to the environment. It was not restarted for more than one and a half year, unable to produce the much needed medical isotopes. Following these two major incidents occurred in ageing RRs, the IAEA launched a multiannual on-going programme to create an international Database on Assessment, Monitoring and Surveillance on ageing of core structure components materials, recognizing that archived data is unavailable for the Member States (MS).

The first recent activity was a Consultancy meeting (CS) conducted in INL (USA) on June 2009, with the topic of Assessment of Core Structural Materials Surveillance Programme of RRs [4]. That meeting was followed by a Technical Meeting (TM), with the identical title, hosted by the Agency on June 2010. Following the TM a TECDOC publication was prepared, including and analysing nineteen (19) contributed papers [5]. Then after, upon the recommendation of the TM, a second CS will be organized on October 2011, with the topic of Integrity Assessment of Research Reactor Core Components for Lifetime Extensions: Process, Status and Future perspective. This meeting will determine the scope and format of a multi-annual Coordinated Research Programme (CRP), including recommendations for the methodology and Database concept to the assessment of RR core structural materials for lifetime evaluation and extension. Furthermore, it is expected from the experts to identify key MS contributors to the CRP on the same topic, to be initiated in 2012.

**ASSESSMENT OF RR CORE STRUCTURAL COPONENTS MATERIAL AGEING**

In order to ensure consistency in the presentation, core structural components are defined as the key parts of the reactor structure that provides any form of support for the reactor core including:

- ❖ Structures that support the static, dynamic and/or seismic loads in the core (e.g. core support grid, frames and weldments to the main reactor vessel or block;
- ❖ Structures that enclose the core and/or define its geometric boundary (e.g. core box, reflector tank etc.);
- ❖ Structures that provide geometric definition within the core (e.g. beryllium reflector, graphite moderator.);
- ❖ Structures that provide a pressure boundary for the core (e.g. reactor vessel);
- ❖ Structures that enclose and/or provide a pressure boundary for experiments that operate in an environment different from that in the core (e.g. loop experiments, thermal columns etc.);

The assessment of the core structural materials can be performed due one of the following issues: (a) Safety related: critical safety component (as consequence of failure), self-motivated or requested by the regulator; (b) Sustainability related: life limiting component, self-motivated by the operator in order to enable a long term operation of the RR.

Core components are classified as Category I or II according to the following definition [6]:
Category I: Equipment of primary importance, not redundant, not easily repairable or replaceable (e.g., reactor vessel, primary coolant system piping).
Category II: Equipment of primary importance, but redundant or can be easily inspected or repaired (e.g., electric power supply, control rods).
Category III: Equipment not primarily important but not easily inspectable or repairable (e.g., primary water purification system).
Category IV: Other equipment (e.g., auxiliary diesel generators).

The significance, consequences and acceptability of accidents related to failure of each component from Category I should be performed as they are critical and potential service life time limiting. Hence, a specific scheme and programme for assessment of core structural material should be prepared by each operator. When safety related critical components should be identified, the operator needs to perform a comprehensive system breakdown, e.g., a Fault Tree Analysis, with clear definitions of accidental top events.

Structural components and their parts can be made of different material and different fabrication conditions (e.g. base, weld, etc...). It is necessary to exactly identify each material of critical components, as degradation might be material dependent. Moreover, the assessment of core structural materials should be based on the original information such as the fabrication data, initial tested properties, approved deviations from specifications, welding procedures and inspection records. The ageing mechanisms should be identified for each material of each critical component. As the degradation mechanisms of core structural materials are primarily driven by operating conditions and operation history, the effects of radiation, chemical interaction with coolant medium, operating temperature and cyclic mechanical loads have a direct influence on the original mechanical properties down to failure or damage of the components. Hence, the relevance and importance of each ageing mechanism should be assessed [6].
Structural safety assessment should identify the relevant degradation mechanisms for critical core structural components. In addition, important parameters collected during the operation should be analysed for indicators of degradations. The following inputs can support the structural safety assessment process:

(1) Loading condition;
(2) Material properties and their evolution with irradiation;
(3) Initial flaw size (NDT);
(4) Flaw size evolution by degradation mechanism (e.g., fatigue, corrosion, etc…);
(5) The integral neutron flux “seen” by the component;
(6) Review of operating data, such as chemistry records, water quality data, and equipment performance data.

The output of the structural safety assessment is considered safety margin against failure, maximum operating condition or an inspection interval.

The challenges related to the process of assessment the core structural material ageing are:

(i) Absence of initial surveillance program, absence of archive material including the detailed information on the actual material used in the construction of the RR, as well as the welding procedures of the metals;
(ii) Unique tailor made RR design, hence database cannot be easily transferred;
(iii) Surveillance specimens inside a RR consume some valuable space for applications and experiments;
(iv) Using the published data generated from nuclear power reactors for identical irradiated material properties can be only indicative, due very different operating conditions;

(v) Available (published) data (e.g., mechanical properties, corrosion thresholds, fatigue failures, swelling observations, etc..) for irradiated materials typical to be used to build the core of RRs can be very sparse;

(vi) Non-existent mandatory specific national standards/regulations to perform age management of RR, especially for surveillance programs. Therefore, almost no available resources for core materials assessment;

Moreover, the present status raises difficulties for national regulatory authorities to accept R&D programmes for core material assessment of RR as: a) Regulators cannot rely on standard documents to set up requirements; b) Regulators cannot rely very much on knowledge and experience from power reactors, which generally constitute to their main activities.

**Compendium of the CS - INL (2009)**

The meeting had the following objectives: (a) to identify key issues on RRs degradation mechanism and their possible impact to the operation (on short and long term perspective); (b) to analyse the situation on monitoring of degradation mechanism, especially for core structural materials;(c) to overview RR surveillance programmes; (d) to summarise the irradiation programmes for testing NPPs RPVs and development of new structural materials (fusion and fission reactors). The experts discussed the following topics [4]:

- A different approach to ageing management of RR, focussed on critical structural components;
- The scientifically challenges related to the assessment of core structural material of RR;
- Material related degradation mechanisms, in particular the fracture toughness.
- Degradation of aluminium alloys (vessel and core grid), corrosion of steels, radiation damage of beryllium reflector/matrix;
- Assessment of core structural material from the licensing point of view;
- The useful information for the operating organisation, seeking for the extension of the RR operational life, e.g., a database of RR with core material descriptions
- The need of information exchange within a designated TM;
- The need of a irradiated material properties database (for a specified alloy, given environment (temp) and history of neutron flux);

It was recognized that adequate archived structural material data is not readily available for many operating RRs. Therefore, providing access to the data that may exist and extension of existing material databases to cover specific applications could help many operating organisations extend the operation lifetime of their RR. The main recommendation of this meeting for the IAEA was to launch a two-steps process in order to address these shortcomings:

(a) To organize a TM on Assessment of Core Structural Materials, with the following objectives:
- exchange and review detailed technical information on the degradation, assessment and ageing management of core structural components and materials;
- identify structural materials of interest for further investigation;
- strengthen international and regional cooperation and networking between scientists and engineers from developing and developed countries on the transfer of knowledge.

(b) Upon the conclusion of the TM, to consider a CRP intended to address the shortcomings and fill in the gaps in the known databases for structural materials subjected to service in the cores of research reactors.

**Compendium of the TM - IAEA (2010)**

The objectives of the TM were:

(i) The exchange of detailed technical information on the assessment and ageing management of core structural materials,
(ii) To identify those materials of interest for further investigation,
(iii) To develop a proposal for a new CRP on the Assessment of Core Structural Materials,
(iv) To identify RR organisations prepared to participate in the proposed CRP.

The meeting was attended by 27 international experts from the following countries and was chaired by Mr. Bob van der Schaaf (Nederlands), while Mr Bob Harrison (Australia) and Mr Alan D'Arcy (South Africa) were appointed rapporteurs of sessions. The IAEA scientific officers responsible for this technical meeting were Dr Andrej Zeman (NAPC) and Mr Ed Bradley (NEFW). The policies, data, analyses and views of the different experts are reported in nineteen contributions that will be published soon as annex to the TECDOC of IAEA [5].

Considering the presented programmes, some were on projected or on-going surveillance plans, where others reported methods of prediction and evaluation. The papers demonstrated the different monitoring approaches used in the assessment of core structural materials degradation. Most of the activities results from visual preventing inspection, although in six cases the activity started post a safety event of coolant leakage. The presentations displayed a wide range of NDT techniques used worldwide [7], to analyse the effect of RI and CI damages on various indicative parameters, such as: dimension changes (i.e., wall thickness) along with DT techniques to evaluate irradiated material mechanical properties. The core materials analysed (in order of frequency) were: aluminium alloys, zirconium alloys, beryllium and austenitic stainless steels. The participants reported their assessments on components such as the reactor vessel and internals, including the pool liner, which its integrity is vital for safe operation, as well as maintaining the cooling in the pool of the spent fuel wet storage [8]. Another recognized critical component, to be assessed, was the beryllium reflector, although it is usually held in a moveable structure, as the disintegration of beryllium due neutron irradiation can cause severe neutron flux distortions and cease the operation.

Table 1[5] is summarizing the presentations, pointing out the RR characteristics, the type of the assessment programme, the topic monitored and the technique used as well as the component monitored, the material of the component and the structure that the specific component belongs. It was demonstrated that in high flux RR the radiation damage effects are considerable higher, reflecting on the mechanical properties tested. Reflector vessels and core tanks are the most frequent tested items were pool liners and safety control systems are less frequent monitored. The TECDOC [5] includes the contributed papers as well as a comprehensive overview of the topic of assessment and monitoring and surveillance of RR's core structural materials ageing**.** The main recommendation derived from the discussion during the TM wais the proposal for a new IAEA CRP on the Monitoring and Assessment of Core Structural Materials of research reactors. A data base of existing materials data will help to fill gaps in locally missing information. Formalization of the needed data exchange is considered to have a high priority. It is identified that a data base is required that addresses the needs of the research reactor operators to have easy access to information supporting their surveillance activities. The most important materials for such a data base are identified as aluminium and zirconium alloys. The data collection and evaluation of high neutron dose mechanical and corrosion properties have the highest priority.

## CONCLUSION

- ✓ There are great varieties in shapes of structures and materials used in the construction of the different RR core components. The reactor tanks and vessels are predominantly constructed from aluminium or zirconium alloys, and the monitoring of these materials is the very important basis for the assessment of the component's integrity.
- ✓ A structural analysis is a crucial part of the safety assessment and ageing management programmes. It is the only possible avenue to pursue when an extension of lifetime is considered.
- ✓ The analyses are only as good as the input data used and it is very important to provide the irradiated materials data based on the integral neutron flux.
- ✓ As this paper is mostly informative on an existing programme, the most important conclusion is that any international contribution of MS, to create a Database on Assessment, Monitoring and Surveillance of Research Reactor's Core Structural Materials Ageing is very welcomed.

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| Country | Reactor(s) | | | | Programmes | | | Monitoring (how? / what? / when?) | | | | | | | Components | | | Materials | | | | Structures | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Representative | Name | Power (MW) | Year of first criticality | Type | Plan | Evaluation | Predictions | Visual | Non-destructive evaluation (NDE) | Corrosion | Wall thickness | Dimensions | Mechanical properties | Post-Accident (Leakage) | Pool liner | Vessel/tank | Control/device | Aluminium | Zirconium | Beryllium | Other materials | Pools | Core support |
| ***Argentina***<br>Durione and Haddad | RA-3<br>RA-6 | 10<br>0.5 | 1967<br>1982 | Pool<br>Pool | | | X | X | | X | | X | X | | | X | X | X | | X | | | X |
| ***Australia***<br>Harrison | HIFAR<br>OPAL | 10<br>20 | 1958<br>*<br>2006 | Tank<br>Pool | <br>X | X<br>X | X<br>X | X<br>X | X<br>X | X<br>X | X<br>X | <br>X | X<br>X | <br>X | <br>X | X<br>X | | X<br>X | <br>X | | <br>X | <br>X | |
| ***Bangladesh***<br>Zulquqrnain | BAEC | 3 | 1986 | Triga II | X | | | X | | | | | | X | | | X | X | | | | | |
| ***Belgium***<br>Joopens | BR2 | 100 | 1961 | Tank | X | X | X | X | X | | | X | X | | | | | X | | X | X | | |
| ***Brazil***<br>Ramanathan | IEA-R1 | 5 | 1957 | Pool | X | X | X | X | | X | | | | | | | | X | | | X | | |
| ***China***<br>Shaoxuan | Qinshan 1 | 900† | 1991 | PWR | X | X | X | | | | | X | X | | | | | | | | X | | |
| ***India***<br>Marugan | FBTR | 40 | 1985 | Enclosed | X | X | X | X | | | | X | X | | | X | | | X | | X | | |
| ***Indonesia***<br>Nitiswati | GA Siwabessy<br>Bandung<br>Kartini | 30<br>20<br>0.1 | 1987<br>1964<br>1979 | Pool<br>Triga<br>Triga II | X | X | X | X | X | X | X | | | | X | X | | X | | | X | X | |
| ***Korea (Rep. of)***<br>Kim | HANARO | 30 | 1995 | Pool | X | X | X | X | X | X | X | X | | | | | | X | X | | | | |

**Table 1: Summarized data from presentations on Assessment of Core Structural Material and Surveillance Programmes [5].**

| Country | Reactor(s) | | | | Programmes | | | Monitoring (how? what? when?) | | | | | | | Components | | | Materials | | | | Structures | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Representative | Name | Power (MW) | Year of first criticality | Type | Plan | Evaluation | Predictions | Visual | Non-destructive evaluation (NDE) | Corrosion | Wall thickness | Dimensions | Mechanical properties | Post-Accident (Leakage) | Pool liner | Vessel/tank | Control/device | Aluminium | Zirconium | Beryllium | Other materials | Pools | Core support |
| ***Latvia*** Abramenkovs | IRT | 5 | 1961* | Tank in Pool | | X | | | | X | | | | | X | | | X | | | X | X | |
| ***Malaysia*** Masood | RTP | 1 | 1982 | Triga | X | | | X | | | | X | | | | | | X | | | X | | |
| ***Netherlands*** Van der Schaaf | HFR | 45 | 1961 | Tank in Pool | X | X | X | X | X | | | | X | X | | X | | X | | X | | | |
| ***Romania*** Ciocanescu | Pitesti | 14 | 1980 | Triga II | X | X | X | X | X | X | | X | X | X | | X | | X | | X | X | | X |
| ***Russian Federation*** Erak | IR-8 | 8 | 1981 | Pool | X | X | X | X | X | X | | X | X | | | X | | X | X | X | X | | X |
| ***South Africa*** D'Arcy | SAFARI | 20 | 1965 | Tank in Pool | X | X | X | | | | | | X | | | X | | X | | X | | | X |
| ***Ukraine*** Revka | WWR-M | 10 | 1960 | Tank | | X | X | X | | | | | X | | | X | | X | | | | | X |
| ***United States*** Unlu | PSBR | 1 | 1955 | Triga | | | | | | | | | | X | X | | | | | | X | X | |
| ***Uzbekistan*** Baytelesov | WWR-SM | 10 | 1959 | Tank | X | X | X | | X | | | X | X | | | | | X | | | | | |
| ***Vietnam*** Nguyen | DNRR | 0.5 | 1963 | Pool | | | | | | X | | | | X | X | | | X | | | X | X | |

**Table 1**: Summarized data from presentations on Assessment of Core Structural Materials and Surveillance Programmes (cont.) [5]