FIRST PERIODIC SAFETY REVIEW OF THE FRM II AFTER 10 YEARS OF ROUTINE OPERATION

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ABSTRACT

The FRM II is Germany's most modern and most powerful research reactor and is operated by the Technical University of Munich (TUM) on its research campus in the North of Munich. Due to its 20 MW thermal power and the very compact core it offers a very high neutron flux for more than 25 beam tube instruments and a set of irradiation facilities. The construction of the FRM II started in 1996 and the reactor achieved its first criticality in March 2004. In the nuclear commissioning phase the FRM II reached its nominal power of 20 MW in August 2004 and the startup cycle was finished end of October 2004. Routine operation was started with the beginning of the second reactor cycle end of April 2005.
According to the German nuclear energy act and a dedicated requirement from the operating license also the FRM II as a research reactor has to perform a regular periodic safety review (PSR) every 10 years. This PSR includes a full description of the facility, a deterministic safety status analysis, a probabilistic safety analysis and a security analysis. The PSR documents were sent in time to the regulatory body and its technical support organization (TSO) in May 2015. The paper presents the graded approach for the PSR for a research reactor in respect to the mandatory German regulations for NPPs, some results of the PSR and the status of the follow up process underway to finalize the PSR.

1. Introduction

The FRM II is a heavy water moderated and light water cooled research reactor located in the North of Munich on the research campus of the Technical University of Munich (TUM) who is also the responsible operator of the reactor facility. Providing 20 MW thermal power it is the most powerful research reactor in Germany and due to its nuclear startup in the year 2004 it is also one of the newest neutron sources not only in Germany but also worldwide.
With its very compact core that is realized with only one single fuel element it offers a very high neutron flux to more than 25 beam tube instruments using not only thermal neutrons, but also cold and hot neutrons from a cold and a hot secondary neutron source. In addition to the scientific instruments the FRM II operates a set of irradiation facilities for the production of radioisotopes and the doping of silicon on a commercial basis.
After the commissioning phase with the first fuel element, routine operation started with the beginning of the second fuel cycle end of April 2005. Besides the date of the first criticality of the reactor in March 2004 for the FRM II the beginning of routine operation is one of the key dates for periodic terms including the periodic safety review (PSR).

2. Legislative framework in Germany

In Germany there is already for many years an obligation stated in the atomic energy act (AtG) [1] for nuclear power plants (NPP) to conduct a PSR in periodic intervals of 10 years. This obligation in § 19a has meanwhile been extended to other nuclear facilities by an amendment to the law and affects therefore also the research reactors in Germany.
The paragraph requests from the licensee of the facility to report the results of the assessment to the regulatory body, but gives no detailed requirements concerning the contents of the PSR and the process to perform it. Therefore there are guidelines published by the federal ministry that is in charge for reactor safety on the structure and contents of a PSR for NPPs. The primary guideline [2] on PSR requests for a full PSR the following parts:

- Description of the facility
- Deterministic safety status analysis (SSA)
- Probabilistic safety analysis (PSA)
- Deterministic security analysis (DSA)

The detailed requirements on the SSA, PSA and DSA are stated in separate guidelines [3], [4], [5] and are preferentially focused on NPPs and their specific design as PWR or BWR type reactors.
Besides the above mentioned legislation and guidelines for NPPs there is no special set of regulations for research reactors in Germany. As a consequence the existing framework of guidelines for NPPs has to be adapted to the special needs of the German research reactors that are also very different as compared to each other. For the FRM II this graded approach based on the existing guidelines was already foreseen by a collateral clause in the operating license of the FRM II [6] that has been granted in the year 2003 before the amendment of the nuclear energy act made a PSR compulsory for all nuclear facilities in Germany.
To perform the PSR in an effective way the intended structure and main parts were discussed and agreed upon with the regulatory body and its technical support organization (TSO) before the beginning of the work. This approach is conformal with the guidelines even for NPPs as the guidelines themselves suggest a consultation with the regulator for clarification of details of the PSR and the expected documents.

3. Structure of the PSR for the FRM II

The structure of the PSR for the FRM II is derived from the proposed structure in the guideline [2] and consists of five volumes. As agreed with the regulatory body the PSR covers the time period from 01.05.2005 until 30.04.2014 and had to be submitted on the 1st of May, 2015. For practical reasons some evaluations (e.g. on radiation protection data) cover in addition the full calendar years 2005 and 2014.

3.1 Introduction and summary

Volume I gives an introduction to the PSR, explains the structure of the documents and gives a general assessment and summary of the results of the SSA, PSA and DSA.
In the introduction the relevant guidelines and their specific application for the PSR of the FRM II are described. For the following aspects the PSR of the FRM II sticks directly to the requirements from the guidelines for NPPs:

- The proposed structure with a preceding description of the facility, a SSA, PSA and DSA is used.
- The PSR is based on the three basic safety requirements (control of reactivity, cooling of the core, confinement of radioactive material) and focuses on level 3 of the defence in depth concept (control of accidents within the design basis).
- The structure of the PSR was discussed and agreed upon with the regulatory body before the start of the PSR process.
- The SSA is split into three reports: A deterministic review and assessment of the safety functions necessary to fulfill the basic safety requirements, a document for the review of very specific and rare events including the concept for emergency actions and

a report on the operational experience of the last 10 years.
- As far as possible documents are used for the assessment that have been submitted in the licensing procedure of the FRM II and therefore are already verified and proven by the TSO of the regulator.
- The PSA will be done according to the guidelines [4] and the underlying descriptions concerning PSA methods.
- The DSA document is done according to the guideline [5] and was oriented to a DSA done for a Bavarian NPP on suggestion of the regulator.

On the other hand the following aspects of the guidelines are dedicated to NPPs and are not suited for the FRM II even in a graded approach:

- The template for the description of the facility from the guideline reflects the structure of systems in a NPP and is therefore not used.
- The appendix from the guideline with a list of relevant initiating events, accidental conditions and beyond design basis accidents for PWR and BWR reactors is not applicable to the FRM II.
- The guideline for the required security measures and precautions for light water reactors (NPPs) is not applicable for the FRM II. Instead of this guideline the licensed security concept of the FRM II is used for the review.

After the introduction to the applicable regulations and the graded approach for the FRM II the structure of the PSR is described in the second chapter of volume I.
The third chapter of volume I gives an overall assessment of the PSR and summarizes the key results of the SSA, PSA and DSA without going too much into details. The idea behind these short summaries of all other volumes is that volume I of the PSR documents is readable as a standalone document like a “management summary”. In case there is a request from outside the regulatory body or its TSO to get information on the PSR, volume I gives an overview on the background, the structure and the main results of the PSR in a short and compact form on less than 15 pages of paper.

3.2 Description of the facility

Volume II contains the description of the facility. While compiling this description it turned out, that the FRM II had already since the licensing procedure, which was finished with the granting of the operating license in May 2003, a very comprehensive documentation. For all buildings, systems and components there are detailed descriptions and schematics available, which have been approved by the TSO of the regulator already within the licensing procedure. The structure and the contents of this documentation also complie with the requirements stated in the associated appendix to the guideline [3] for NPPs.
At the FRM II these documents originating from the licensing procedure that was finished more than 10 years before the first PSR are continuously updated in case of modifications to the buildings, systems or components and are checked again by the TSO. Therefore the documents reflect the current status of the facility.
The description itself consists of a textual part that starts with a general overview on the design and safety concept of the FRM II followed by a description of all buildings and systems of the facility. In addition to this 295 page document around 160 appendices with detailed descriptions covering all systems of the FRM II are added in five additional folders.

3.3 Deterministic safety status analysis

Volume III contains the deterministic safety status analysis. The volume consists of three separate reports that are added as appendices to the main textual part. The first two of them were compiled by the company which designed and delivered the FRM II including the necessary documentation for the licensing procedure.
The first report covers the deterministic review and assessment of the safety functions necessary to fulfill the basic safety requirements. As a first step of the analysis the current spectrum of events and accidents within the design basis is defined. Based on this spectrum the necessary safety functions and safety systems to handle the events are derived and evaluated concerning their relevance and their required response time. Besides the event spectrum

already used in the licensing procedure of the FRM II the IAEA Safety Standard NS-R-4 „Safety of Research Reactors“ [7] is used additionally in respect to the generic events stated in this standard document. As far as there are existing and by the TSO already approved documents available, these are used for the assessment. In the case there have been modifications to safety relevant systems after issuing these documents, the modifications are reviewed in detail.
The second report covers the review of very specific and rare events including the concept for emergency actions. This includes the scenarios airplane crash, blast wave from external explosions and ATWS. These events are because of their very low probability of occurrence not within the design basis and are consequently assigned to safety level 4 as beyond design basis accidents (BDBA).
The third report contains a review and evaluation of the operational experience of the last 10 years (2005 – 2014). The evaluation was done for the subject areas organization, operation, education, maintenance, radiation protection, return of experience, emergency planning, periodic in-service inspections, load cases, lifetime management and reportable events. Most of the information is already collected year by year for then comprehensive annual technical report of the FRM II. So the report for 2005 – 2014 compiles and evaluates already existing data.

3.4 Probabilistic safety analysis

Volume IV contains the probabilistic safety analysis for the FRM II. In the licensing procedure of the FRM II the applicable regulations for a research reactor did not require a full PSA. Therefore the PSA document done but the contractor was not checked and approved by the TSO of the regulatory body.
For the PSR the former contractor was mandated to perform a full PSA level 1 for the operational and non-operational state and a PSA level 2 common for both operational states of the reactor. As the PSA was done by an external contractor, the textual part of volume IV is very short and the PSA itself is a report that is added as an appendix to the document.

3.5 Deterministic security analysis

Volume V contains the deterministic security analysis. Because of the confidentiality of the information contained in this volume it was prepared separately from the other volumes. After a description of the major differences of the FRM II compared to a NPP and its security requirements, the security equipment and the security measures of the FRM II are described. Based on this information a review and assessment of the security status of the facility is performed.

4. Results of the PSR

This chapter gives a short overview on the results of the SSA, PSA and DSA as they were written down in the revision 0 of the documents that were submitted to the regulator and its TSO. Finally there is also a short note on the ongoing follow up with the TSO on the way to the final revision 1 set of PSR documents.
The **SSA** concludes that the safety systems of the FRM II fulfill the safety requirements and are adequate to cover all events from the derived spectrum for safety level 3. There are no deviations or deficits in the safety concept and design of the systems relevant to safety. Events that are not already excluded by preventive measures are handled effectively and reliability. The review of the measures against very specific and rare events and the emergency actions shows, that for an airplane crash and a blast wave caused by an external explosion there is sufficient precaution to avoid or at least reduce the release of radioactive material to the environment even in the case of a partial core melt scenario. Due to the redundant and diverse shutdown systems of the FRM II an ATWS scenario does not have to be assumed for the FRM II. The evaluation of the operational experience of the last 10 years of routine operation showed, that the FRM II was operated safely and with a high availability to its users and customers. Because of continuous improvement by technical modifications of the facility and organizational and administrative adaptions to changing requirements the safety level of the FRM II was not only kept but even improved over the last decade.
The **PSA** results in a core damage frequency (CDF) of $4.2 \cdot 10^{-6}$/a calculated over all initiating events of the operational and non-operational state of the reactor. The major contribution

to this value comes from the common cause failure of both natural convections flaps in the primary cooling system, that have to open some hours after the reactor shutdown and the additional failure of the manual restart of at least one pump of the primary or the emergency cooling circuit. This CDF value is far below the CDF value that is required by the IAEA for new designed NPPs. The frequency for the release of radioactive material in the environment due to a failure of the filtered ventilation system that keeps an underpressure condition in the reactor building and working confinement of the building by closing of all ventilation valves sums up to $5.3 \cdot 10^{-9}$/a. Under the condition that even the closing of the ventilation valves fails, the calculation results in a value of $4.6 \cdot 10^{-10}$/a. Both values are far below the international values for new NPPs.
The **DSA** concludes that the structural, technical and administrative measures of the FRM II are in accordance with the licensed security concept and are suited to prevent any consequences from relevant attacks. Because of the confidentiality of the security measures no more details are disclosed.

The PSR volumes that in sum comprise 5800 pages were submitted in time with an official letter dated April 30th, 2015 to the regulatory body and in parallel to its TSO.

Fig. 1: The PSR team of the FRM II with the finished PSR documentation.

After the PSR documents were submitted, the TSO started to check all the volumes of the PSR in parallel. In a meeting end of January 2016 the TSO reported to the regulator and the FRM II on the status of the assessment of the submitted documents. Concerning the description of the facility the TSO handed over a list of minor change requests. All these requests are included meanwhile in the documents and the final revision 1 of volume II is finished. As already mentioned above the two SSA reports on the safety functions (safety level 3) and rare events (safety level 4) are mostly based on the approved documents from the licensing procedure of the FRM II and the SSA reports are referencing to them. Because of this the TSO requests a statement for each reference whether the used approach and calculation methods including the applied software codes are “state of the art” today. After some discussion it turned out as a possible solution, not to extend the existing reports, but to add a forth appendix to the SSA that deals with this topic. The work on this additional document is still ongoing. For the PSA report the TSO compiled an extensive list of points to discuss. As the PSA was done by an external contractor, the list was handed over to him and there has been already a topical meeting to discuss and clarify these points. Also for the DSA the TSO requested additional calculations e.g. on the limited external exposition caused by release of radioactive material due to the low inventory of nuclear fuel in the FRM II.

5. Summary

The FRM II had to perform a full PSR after 10 years of routine operation in 2015. According to the German regulations the PSR documents consist of a description of the facility, a deterministic safety status analysis, a probabilistic safety analysis and a deterministic security analysis. The PSR was performed using the German guidelines for NPPs. Where necessary

a graded approach was used, because the guidelines for NPPs are not directly applicable for a research reactor. The PSR documents were submitted in time to the regulatory body and showed that the FRM II fulfills all relevant safety requirements. The assessment of the extensive documentation by the TSO is still ongoing. After including all hints and requests from this assessment all documents will be released in a revision 1. According to the German regulations these set of documents can be used as basis for the next PSR that is due in the year 2025.

6. References

[1] Gesetz über die friedliche Verwendung der Kernenergie und den Schutz gegen ihre gefahren (Atomgesetz, AtG), 23.12.1959, zuletzt geändert am 01.06.2017, BGBl.I 2017, Nr. 33, S. 1434

[2] Leitfäden zur Durchführung von Periodischen Sicherheitsüberprüfungen, BMU, RS-Handbuch 3-74.1, BAnz. 1997 Nr. 232a, 18.08.1997

[3] Leitfaden Sicherheitsstatusanalyse, BMU, RS-Handbuch 3-74.1, BAnz. 1997 Nr. 232a, 18.08.1997

[4] Leitfaden Probabilistische Sicherheitsanalyse, BMU, RS-Handbuch 3-74.3, BAnz. 2005 Nr. 207, 30.08.2005

[5] Leitfaden Deterministische Sicherungsanalyse, BMU, RS-Handbuch 3-74.2, BAnz. 1998 Nr. 153, 25.06.1998

[6] Teilgenehmigung nach § 7 Atomgesetz (AtG) zum Betrieb der Hochflussneutronenquelle München in Garching (FRM-II) - 3. Teilgenehmigung -, StMLU, Az. 93b-8812.2-2000/1-8, 02.05.2003

[7] IAEA Safety Standard „Safety of Research Reactors", Safety Requirements No. NS-R-4, IAEA, 2005