FRM II: UPDATE ON THE STATUS AND OUTLOOK

A. PICHLMAIER, F. JESCHKE, R. SCHÄTZLEIN

Technical University Of Munich, ZWE FRM II
Lichtenbergstr. 1, 85748 Garching, Germany

Due to a chain of unfortunate events, FRM II has not been in user operation since March 2020. The restart is foreseen in late 2023 if everything goes according to schedule. The paper will sum up the issues that lead to the actual situation, describe the main activities in 2022, give an outlook for 2023 and the perspective for return of the FRM II reactor to regular scheduled power operation.

1 Introduction

The Technical University of Munich (TUM) operates the FRM II, a heavy-water moderated and light-water cooled pool-type research reactor with 20 MW thermal power. It uses one single fuel element which provides 60 full power days. The FRM II is mainly used as a beam tube reactor for neutron scattering experiments. However, it also has a dedicated neutron activation analysis beamline, a tomography facility, a beamline of slow positrons and one primarily for medical purposes. It is also used for radioisotope production and silicon doping. Criticality was reached for the first time in 2004, routine operation started in 2005.

2 Events leading to the situation at FRM II in early 2023

In March 2023 the FRM II had a sad reason to celebrate: 1111 days without power operation. The legitimate question is: how did this situation develop?

The situation in 2019/2020

Already the year 2019 had been a difficult one for FRM II. Due to transportation issues between France and Germany for a long time no fresh fuel could be transported from the manufacturer in France to the FRM II in Germany. These questions were temporarily resolved in 2019 and fresh fuel assemblies were delivered to FRM II. In early 2020 one 60-day reactor cycle was run according to schedule. Two events almost equally changed life at FRM II, namely the Covid-19 pandemic and the reportable incident "Emission of the radionuclide C-14 above authorized limits". The Covid-19 pandemic imposed serious travel restrictions making it almost impossible for users to travel to FRM II. But also from the operations point of view it was a serious challenge to maintain the minimum personnel on site as required by the applicable rules and regulations of safety and security. For the C-14 event it has to be stated the total emission was very low and comprised only about 23 % of the maximum allowed by the radioprotection ordonnance. However, the limit imposed on FRM II by its license is as low as 20 % (or 2E10 Bq/a). With this limit surpassed while drying spent cleaning resins used in the heavy water system, no more reactor operations could be carried out in 2020. The hole event is quite complicated and basically a combination of human error under Covid-19 conditions. Consequences at FRM II were mainly the restructuring of the training program for the personnel and several technical measures including the construction of a new drying facility for the heavy water resins.

The situation in 2021

Details have been given e.g. in our contribution to the conference RRFM 2022 [2]. This is a short summary of the most important events.

With the consequences resulting from the C-14 event mainly resolved, FRM II was ready to restart in 2021. During restart, at about 10 % of nominal power, the reactor unexpectedly scrammed, triggered by an increase in the pressure of the system of could deuterium of the cold neutron source (CNS). This event was followed by a period of detailed analysis of the causes where finally a Cd-tube could be identified as the main cause of the problem. This tube is part of the Inpile-section of the CNS. It is mounted around the (never put into operation nor even completed) neutron guide (“SR13”) for very cold/ultra-cold neutrons (about 50 m/s) coming for the cold source, to shield the D_2/He heat exchanger from the not negligible amount of thermal neutrons (about 10E10/cm²/s). The Cd-tube had slid down the SR13 and was now at the bottom of the Inpile section of the cold source and partly in the reservoir of liquid D_2 where it was constantly heated by the radiation from the reactor core thus leading to an increase of D2-evaporation, in turn an increase in pressure and finally a scram of the reactor. With this diagnosis it was clear that no reactor operation could be carried out and the inpile section of the CNS had to be removed. The FRM II is licensed to run with either the CNS functioning or without it, but not at any state in between the two. By the end of the year, the removal of the CNS from the moderator vessel was completed and the reactor once again ready to restart. More details are given e.g. in our paper to the conference RRFM 2021 [1].

The situation in 2022

When getting ready to restart the reactor in early 2022, a tiny amount of water was detected in the leak-detection-system JFT. This system surveys most joints or systems in contact with heavy water. It is designed to contain any leakages of heavy or light water. This leakage was very small: one drop of water every three to five minutes at the most. However, operational procedures are clear: such leak needs to be fixed before a restart of the reactor is permissible. A detailed investigation revealed that the source of the leakage was the so called “Zentralkanal” (central channel). In more detail, the leak could be located at the compensator, a double bellow that serves to compensate the unavoidable variations in length due to thermal effects or vibrations. The central channel in general is a formidable component. It is entirely made from AlMg3 (EN AW-5754). The component is about three meters long with 30 cm diameter. The compensator is an integral part of it. The central channel serves several purposes:

- Enclosure of the cooling medium (H_2O)
- Separation of cooling and moderating media (H_2O/D_2O)
- Coolant guide for cooling the fuel element JKA
- Positioning of the fuel element
- Support of the control rod JDA (without drive)
- Ensuring coolant supply to the control rod
- Ensuring the mobility of the control rod
- Support of the solid absorber
- Ensuring free access to the fuel element for refueling after dismantling of internals

Yet it is designed replaceable and meant to be exchanged regularly - but this was never done before and foreseen initially for 2024. The fabrication had already been initiated some years ago but had never made it to the top of the priority list. Therefore, at the time of the event, it had been only partly completed. At the time of writing, it will be still months before the new component will be ready and at the FRM II. Similar to the cold neutron source, nobody had seriously expected its replacement before 2024. So here we are: CNS is removed and central channel not replaced or even fabrication completed at the time of writing. There are more months ahead to wait for the reactor restart.

Fabrication of the central channel is time consuming

What does it make so special and demanding to fabricate the Central channel in general and the compensator in particular? The compensator is made of the material EN AW-5754 (AlMg3). This is a common material for research reactors. In fact, most of the Aluminum components in the neutron field of the FRM II are made of it. However, very few manufacturers have ever undertaken to use it as compensator and FK1-component (this is the highest class of components relevant for safety at the FRM II). Without going into details: this means that a lot of effort goes into the qualification of material, of procedures and of the manufacturer, and that a lot of involvement of the regulator’s technical support organization and overall a lot of time-consuming qualification- and documentation-work is required.

Note that the central channel in total is almost three meters long and forms with the two compensators one single component.

Some of the biggest challenges in manufacturing the central channel are:

Get qualified material. The material needs to be accompanied from the furnace to the finished component by the TSO. Only very few aluminum smelters can produce the small quantities a research reactor needs and typically can afford.

Weld the Aluminum. Welding Aluminum is never easy. To get it nuclear qualified is even more demanding. The required method of TIG-welding did not work on the qualified material available. Therefore, two paths were pursued: qualify a different welding technique – finally, friction stir welding turned out to be promising – and get qualified material.

At the time of writing, both of these questions have been addressed but not yet solved completely. Afterwards, the central channel still needs to be made. This again is a lengthy procedure requiring some 50 individual steps every one taking to complete roughly from a day to a week. Since basically all of this is prototyping, a lot can go wrong in the process.

The Figure 1 shows a demonstrator compensator (full size), Figure 2 a sketch of the bottom part of the central channel with the location of the compensators.

Figure 1: Dummy Compensator (demonstrator component)

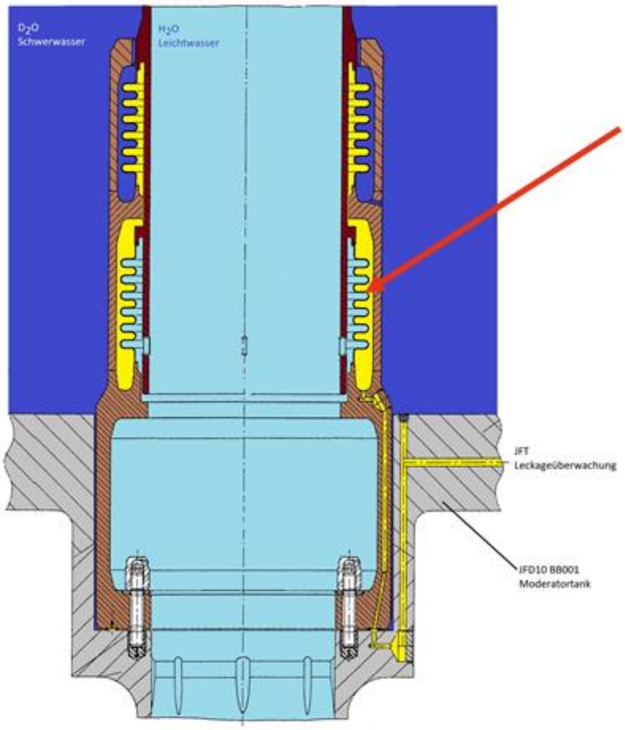

Figure 2: Bottom part of the central channel JEC in brown color. Light water light blue, heavy water dark blue, leak detection system JFT in yellow. Moderator vessel JFD in grey. The red arrow in the right marks the compensator with the approximate position of the leak.

3 Other main activities

At FRM II daily business continues almost as usual. About 1600 in-service inspections were carried according to the applicable inspection-plan, of which about 500 with the TSO involved. About 50 modifications of the installation were initiated or completed and finally, the permission to build a facility for the production of 99Mo was granted. While construction work for the 99Mo production facility is an ongoing project, the required heat exchanger was mounted immediately after the license had been granted, cf. Figure 3 . This heat exchanger is required to transfer about 400 kW of heat produced during the irradiation of the uranium targets to the secondary cooling loop of the FRM II. The completion of the whole 99Mo project will take some more years.

With the discovery of the failure of the central channel the FRM II faced a situation of continued shut-down for at least another year. In order to make the best out of this situation, the 10-year inspections, due normally in 2024 and requiring a lengthy reactor shut-down to complete, were shifted to 2022. These inspections concern mainly the major (pressure-)vessels (e.g. moderator vessel with all its components, secondary sources, heavy water storage, …) that need to be checked by pressure test and visual inspection or compensatory measures. Based on experience gained in 2014, it was assumed that at least six months would be necessary to complete this task, especially also because these activities had not yet been prepared ahead of time as they normally would have been.

The following groups of components were inspected:

- Beam tubes (pressure test and visual inspection)
- Different compartments of the hot neutron source (pressure test, visual inspection and compensatory measures)
- Upper part of central channel (visual inspection)
- Check valves and rupture disks in the moderator system (general overhaul including pressure test and visual inspection)
- Moderator tank (pressure test and visual inspection)

All in all about 30 such inspections were completed on budget and on schedule. All of these were carried out with involvement of the TSO. No deviations with relevance for safety were discovered.

The successful completion of these inspections is an important prerequisite for another ten years of reactor operation.

Figure 3: Heat exchanger of the 99-Mo system, mounted in front of the primary/secondary heat exchanger in the so called primary cell of FRM II.

4 Conclusion and Outlook

Rumor goes that even the unsung heroes of the commissioning times of FRM II have had a hard time building the central channel. So have we. Although designed replaceable, the FRM II is not there yet. If everything goes to schedule the new central channel will be at FRM II in late 2023. It then will be mounted and the whole reactor put back into operation. All of the above are solvable yet challenging tasks that will keep FRM II busy alas not in power operation for the reminder of the year 2023.

5 Acknowledgements

The authors would like to thank for fruitful discussions and valuable hands-on work the operational groups at FRM II. Especially E. Ernst, P. Jüttner, M. Kreß, V. Zill (engineering), A. Wirtz, M. Fuß (CNS, hot source), A. Lochinger, K. Höglauer (reactor operations), E. Krapf (health physics), M. Benedikt, J. Favoli, S. Polat (occupational safety), U. Kappenberg (project management), B. Pollom (change request management, documentation), A. Röhrmoser (neutronics and activation calculations), N. Wiegner, C. Ziller (reactor pool operations), W. Bünten, U. Brunner (quality management). Former colleagues, in theory already enjoying retirement, did not hesitate to contribute with knowledge and experience, first and foremost D. Päthe and A. Schölderle. Colleagues and friends from the neutron sources at ILL, PSI, Delft, Mol were ready to help with advice and support. Last but not least, we would like to acknowledge the patience and continued support for the FRM II by all its stake holders, especially the scientific user community, the TUM Board of Management, the Bavarian Ministry of Science and Art (StMWK) and the German federal ministry of education and research (BMBF).

6 References

[1] CARBON-14, COLD SOURCE, CYCLE OF FUEL AND THE CORONA PANDEMIC – FRM II OPERATOR'S CHALLENGES IN THE YEARS 2020/21
A. Pichlmaier, A. Backs, F. Jeschke, P. Link, C. Reiter, Z. Revay, A. Röhrmoser, R. Schätzlein, B. Schillinger, M. Schulz, S. Sebold, C. Stieghorst, T. Neuwirth, A. Wirtz RRFM 2021 Helsinki, https://www.euronuclear.org/scientific-resources/conference-proceedings/

[2] FRM II: COLD SOUCE ISSUES, DIAGNOSIS, REMOVAL, OUTLOOK
A. Pichlmaier, V. Hutanu, F. Jeschke, R. Schätzlein
RRFM2022 Budapest, https://www.euronuclear.org/scientific-resources/conference-proceedings/