CH04A0046

EXPERIENCES FROM OPERATION, SHUT DOWN AND DISMANTLEMENT OF THE MTR-RESEARCH REACTOR SAPHIR

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1. Introduction

The swimming pool research reactor SAPHIR (MTR type) became operational in 1957 on a power level of 1 MW. For 37 years is was the strongest neutron source within Switzerland for research purposes and industrial applications. The power level of 10 MW was reached in 1983 following the demands of the different facility users.

In the framework of the RERTR program the different steps of reducing the fuel enrichment were practically applied [1,2]. Because of the relative high U-235 content of the elements (HEU: 280 g/element; MEU: 320g/element and LEU: 412 g/element) the core configuration and the cooling conditions have to be considered very carefully. A number of problems could be solved by improving the loading procedures and by modifications of the cooling circuits.

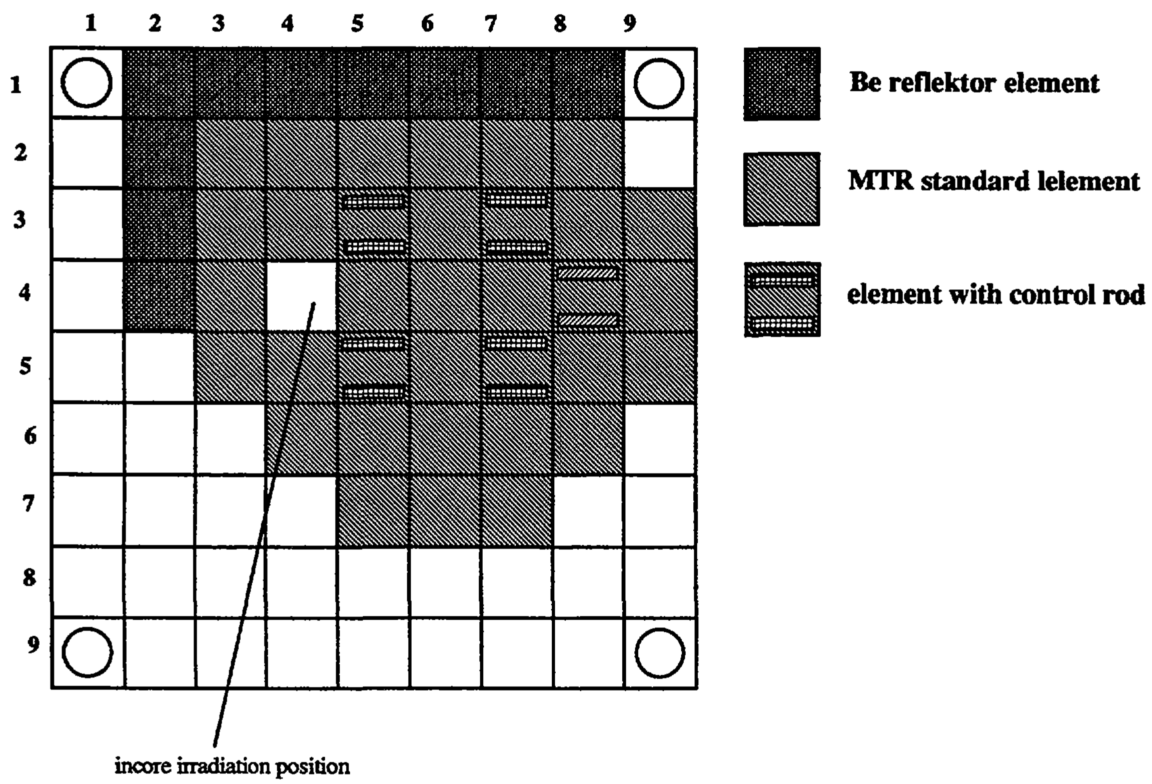

Fig. 1: Core configuration of SAPHIR on a grid plate of 9 * 9 fuel element positions

In 1994 it was decided to shut down the reactor. The owner of the facility (PSI) plans the decommissioning in several steps, starting with shipping all spent fuel elements back to their origin country USA and disposal in the DOE storage facilities. Considerations regarding criticality safety during storage of the fuel elements in the reactor pool, handling procedures and shipping in suited containers were performed. The decommission of the reactor facility will be done during the next years depending on the demands of the future users of the building and the advances in the licensing procedure.

2. Core design and operation

The operation of the reactor SAPHIR was dedicated to the continuos supply with neutrons on a high flux level for users under the boundary conditions of high fuel burn up and safe operation, regarding radiation protection and emission of activity. In this operation mode, about 6000 hours reactor operation per year could be achieved. The fuel burn up reached between 60 and 70% depending on the type of fuel (HEU, LEU).

A typical SAPHIR core is shown in fig. 1, indicating a partly beryllium reflected core in direction to the neutron beam tubes and a relatively open core to the opposite side. This configuration was not only caused by a lack of sufficient Be reflector elements but mainly due to the possibility of flexibility for irradiation equipments and experiments with fast neutrons. Empty positions inside the core enabled incore irraditions on a high flux level.

2.1. Operation conditions regarding coolant flow

The application of more accurate calculation methods showed unexpected high non uniformities of the power density distribution in LEU-fuel elements next to watergaps due to withdrawn control rod absorbers or water reflected elements. The corresponding heat transfer regime with the given flow rate resulted in a lower safety margin to onset of nucleate boiling and flow instability under conservative assumptions. As a first consequence, the maximum thermal power was reduced from 10 to 6 MW until the implementation of constructive measures to increase the coolant flow velocity in the core.

A higher flow velocity was achieved by increasing the speed of both reactor coolant pumps to their maximum. The higher flow rate in the pool induced stronger turbulences, which destabilised the inactive warm water stratification on the pool surface and caused higher radiation levels. This problem was solved by distributing the coolant flow into the pool via a modified diffusor in a more uniform and laminar regime and by the installation of an electric heater (10 kW) in the warm water outlet at the pool surface.

2.2. Core conversion experiences

Because of the relatively large amount of fuel elements available of all three types of enrichments, the conversion to low enriched reactor cores was not really completed by switching to only one pure core. Indeed, mixed cores were used in routine operation over several years. Having in mind the occurrence of high power densities of new fuel elements (especially LEU), core loading procedures were established based on calculations with the reactor code system ELCOS [3], flux distribution measurements and operational experience in core loadings over many years.

Especially the calculation of the power density distribution provided the possibility to predict „hot positions" in a configuration, which was corrected in most cases by shuffling of some elements. In the last years of SAPHIR operation, nearly all core loadings were precalculated, before the operation on power level started. Most problems occurred near the water filled incore positions and at the core boundary, when fresh fuel was in direct contact with the water reflector. At these positions the local coolant flow at the plates is reduced additionally because of the missing side plate of an adjacent element.

3. Utilisation of the facility and experiments at SAPHIR

The research reactor SAPHIR was operated as a multipurpose facility for neutron scattering experiments (5 spectrometers at beam lines with thermal neutrons), different irradiation experiments, neutron activation analysis, isotope production, neutron radiography and a radiochemistry facility [4]. Furthermore, it was a tool for education of students and the staff of nuclear facilities (mainly power plants) during the shut down periods.

Irradiation were performed for silicon doping under commercial contracts for ingots up to 4" diameter. The irradiation experiments were carried out for investigations of the material behaviour of structural materials of nuclear power plants and fusion reactor walls as well.

Most of the produced isotopes were : I-131,Co-60, Na-24, Sm-153, Re-186, Y-90, Ag-111 and Ta-182. Techniques and special capsules were developed for the generation of this different materials.

4. Problems after the shut down of the reactor

4.1. Criticality safety

After the decision to shut down the reactor permanently, most of the fuel elements from years of operation were stored in the reactor pool. Whereas a lot of them reached the burn up limits, a total amount of low burned up fuel, suited for about two critical loadings remained in the pool also. Therefore, the storage, movement and reloading had to prescribe on the basis of criticality considerations. It was found that the storage racks at the pool wall could be used without restrictions. To be sure that fuel elements couldn't be placed in a reactive configuration on the reactor grid plate it was locked by a special mechanical construction.

A minimum of about 6 licensed persons, familiar with the reactor and the fuel movement operations is necessary for all procedures with fuel, including the transportation to the final disposal.

4.2. Inventory of fuel and fission products

It is planned to ship all spent fuel elements to the Savannah River repository facility within the framework of the Environmental Impact Statement (EIS) of the Department of Energy of the USA. A first shipment of SAPHIR elements reached the USA in October 1996. The final shipment is scheduled for early in 1997. The specification of the fuel inventory was done also by calculations based on the code ORIGEN-2 under consideration of the fuel burn up history. Measurements of burnup were done in the past by gamma spectroscopy and by reactivity methods [5].

4.3. Transportation casks

For shipments of the spent fuel elements, different types of certified containers are in use world-wide. The residual SAPHIR elements are foreseen to be transported with TN-7/2 containers of the German company Nuclear Cargo Service (NCS). In the past, this casks were used for HEU elements only. To get the licence for using the containers for elements with lower enrichments and mixed loadings with elements of different enrichments, criticality investigations had to be performed. This calculations were done by means of the

2D transport code BOXER of the code system ELCOS, which is validated for such purposes.

It could be confirmed that TN-7/2 containers, allowing transportation of up to 64 MTR fuel elements, do not exceed the prescribed criticality limit (0.95) under standard and accident conditions. Contrary to the behaviour of infinite compositions of MTR elements in light water where HEU configurations show higher k_∞ than LEU, for the transport container geometry the effective eigenvalues of LEU reach the highest values. Furthermore, it could be shown that any change of the distance of the fuel plates (by external or internal forces) will enlarge the margin to criticality.

4.4. Storage facilities

Some investigations were done for compact storage facilities suited for MTR elements. This storage racks with absorbing side plates made of borated steel, could be very flexible and allow infinite storage volumes of fresh and burned MTR elements.

As there is no further demand for SAPHIR fuel storage in the future the storage racks were not manufactured. However, the results of the investigations and the design of the casks are available for other users. The borated steel plates are available for potential users.

5. Strategies of the dismantlement

After all fuel will be removed from the reactor pool, only the activation product of the reactor installations and experimental equipments has to be considered. From this moment on there is no potential of a nuclear excursion but only the radiation protection problem of irradiation by activation products stored in the pool. Some beryllium reflector elements could be used in other reactor facilities, but their radioactivity has to be considered in the case of transportation.

The level of activation and the amount and categories of activated materials will be analyzed by calculations and measurements as well. After those inventory estimations, the path of each individual component will be specified and the disposal procedure proposed to the safety authority. In parallel to the dismantlement of components, the pool water quality has to be maintained continuously in order to avoid corrosion.

6. Conclusions

Practical experiences with mixed MTR cores during operation on a high power level and the handling of the fuel after the shut down were demonstrated supported by calculations of the different fuel assemblies. From this investigations, some general evaluations concerning MTR fuel could be derived.

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