SAPHIR, How it ended

R. Brogli, J. Hammer, L. Wiezel, R. Christen, H. Heyck and E. Lehmann

Laboratory for Reactor Physics and Systems Engineering

ABSTRACT

On May 16th, 1994, PSI decided to discontinue its efforts to retrofit the SAPHIR reactor for operation at 10 MW. This decision was made because the effort and time for the retrofit work in progress had proven to be more complex than was anticipated. In view of the start-up of the new spallation-neutron source SINQ in 1996, the useful operating time between the eventual restart of SAPHIR and the start-up of SINQ became less than two years, which was regarded by PSI as too short a period to warrant the large retrofit effort.

Following the decision of PSI not to re-use SAPHIR as a neutron source, several options for the further utilization of the facility were open. However, none of them appeared promising in comparison with other possibilities; it was therefore decided that SAPHIR should be decommissioned. A concerted effort was initiated to consolidate the nuclear and conventional safety for the post-operational period.

1 What was SAPHIR?

SAPHIR was a swimming pool reactor using MTR fuel elements. It went critical in April 1957 and initially operated at a power level of 1 MW. After several modifications and improvements over the years, the power was successively increased. From January 1984, SAPHIR operated at a thermal power of 10 at MW. The typical operation schedule was three weeks full power followed by one week for reloading and low power operation. Thus, a total of about 270 days of operation per year was achieved (see Fig. 1). The reactor staff consisted of about twenty licensed persons (see Fig. 2).

At full power operation the reactor was mainly used for:

- Neutron scattering experiments – solid state physics experiments for which three double- and two triple-axis spectrometers were in operation
- Isotope production – for medical and industrial applications
- material testing – fuel irradiation experiments (FILOS), irradiation of Low Activation Materials (LAM) and irradiation of pressure vessel steel (STILO);
- activation analysis
- silicon doping and other irradiation services; and
- irradiation testing of low enriched MTR fuel elements (RERTR program).

During the low power operation phase the reactor was used for training and education of power station operating personnel and students ("praktika"). In addition to the performance of experiments, improvements of the reactor and its safety systems were also accomplished during the low power operation. These various applications of SAPHIR are shown in Fig. 3.

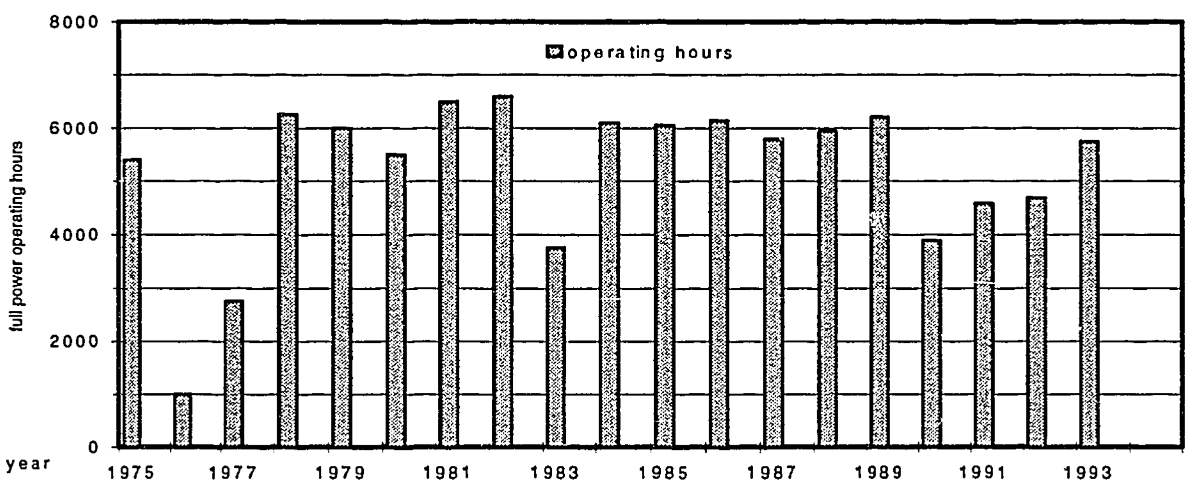

Fig. 1: SAPHIR full power operating hours from 1975 to 1994

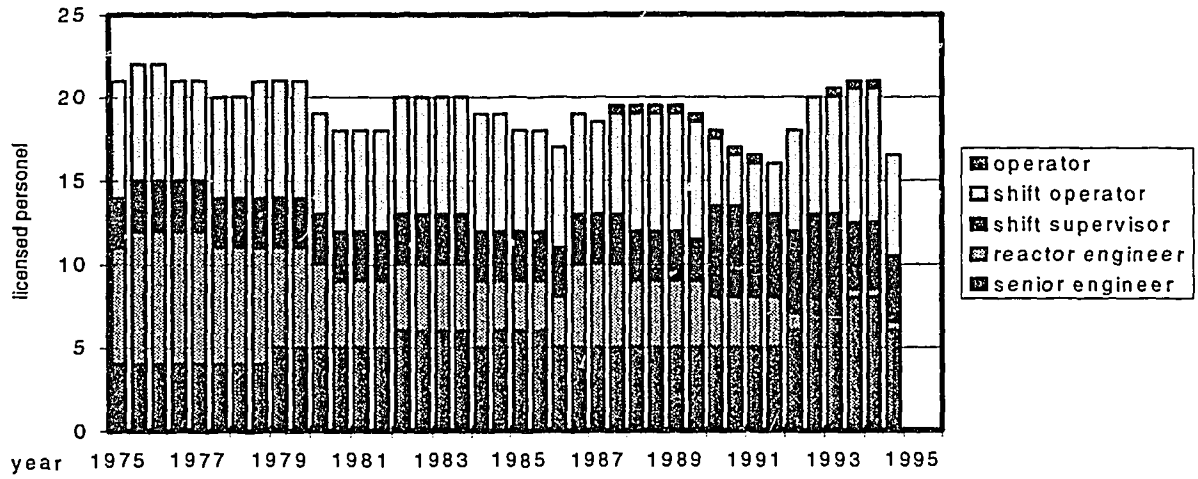

Fig. 2: SAPHIR licenses during two decades

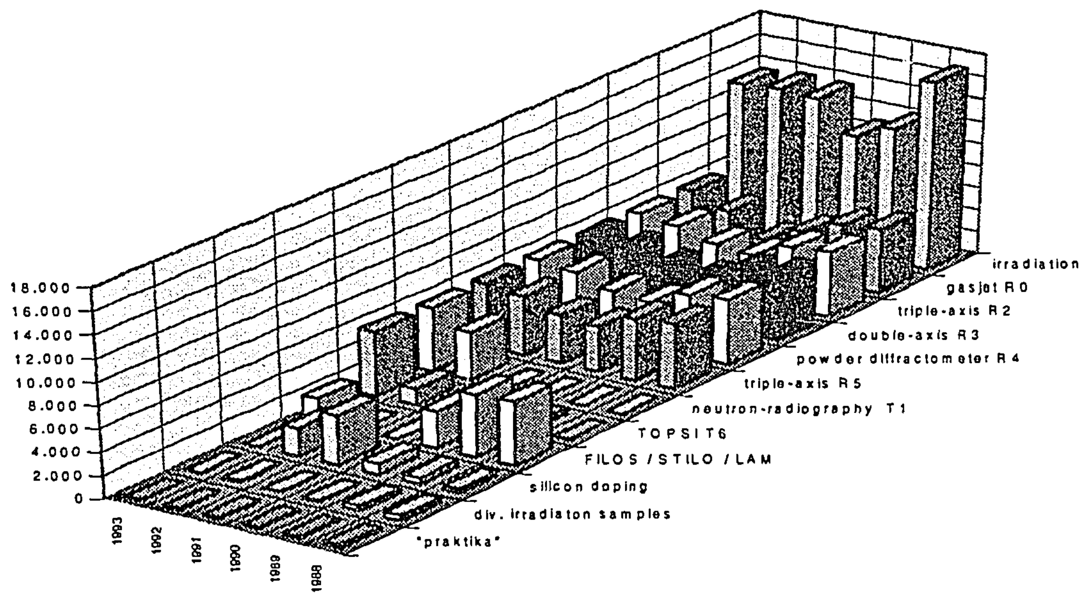

Fig. 3: SAPHIR experimental program 1988 to 1993, R0-R5 and T1/T6 are different beam line designations hours of utilization

2 SAPHIR, the Alternate Neutron Source?

Since the mid-eighties, PSI has been developing and building a new neutron source, the spallation source SINQ at the 590 MeV proton accelerator. This neutron source, scheduled to start its operation in 1995/96, will provide a broad spectrum of neutrons, including very cold neutrons, to its users. The predominant SAPHIR users, those involved in neutron scattering experiments will utilize, in the future, SINQ as their main source of neutrons. In order to evaluate the interest and the possible necessity of SAPHIR operation after the SINQ-start-up, a meeting with all the SAPHIR users was held in August 1992.

The various research groups expressed their needs and their financal support potential for the operation of SAPHIR after 1996 (in Table 1 the degree of needs are indicated with 1-3 crosses X). It was concluded that without the availability of a group to design and perform the irradiations at SAPHIR, there was little demand for high fluences. There was a potential interest for high fluxes and short irradiations times, expressed by university research teams, but without any possibilities for any support by these teams. The strongest SAPHIR need was expressed by the

Application	Low Flux	High Flux Irradiation Time		Support Potential	Comments
		Short	Long		
Education, Demonstration	XXX			XX	The reactor-operator school needs a reactor for training (use ~10-15 days per year)
Medicine; Production of Therapy-Nuclides		XX	(X)	X	Interesting for research, no further commercial isotope production
Neutron Scattering	X		X	—	SAPHIR as a backup for SINQ
Neutron Activation Analysis, NAA		XXX		—	Irradiations for university research institutes (strong interest but little support capabilities)
Neutron-Radiography	X	XX		—	Support for university research, industries
Fuel and Component Test Irradiations			XX	(XX)	Strong interest, but subject to the availability of an irradiation technology group (not available at PSI)
Conclusions:	– Little demand for high fluxes over long periods. – More demand for short irradiations, but little commitment for financial support. – Difficulty to maintain a good staff (responsible and creative), if the operation has little potential and is not challenging.				

Table 1: SAPHIR-Utilization opinion of the users

utilities, for training and demonstration purposes (10-15 days per year). In view of the lack of an overwhelming demand for SAPHIR utilization, the very small outside support, and the considerable cost of operation and the responsibility for the nuclear facility, PSI decided to shut down the SAPHIR reactor after the anticipated start-up of SINQ as a reliable source at the end of 1996.

3 SAPHIR Safety and Safeguard Deficiencies?

Over the years, SAPHIR has accumulated several deficiencies, a few caused through operation actions but for the most part due to increased safety and safeguards requirements:

- Renovation and expansion of the reactor-protection system (a requirement of the safety authority, HSK).
  The SAPHIR reactor protection system (RPS) ensured that, during operation, the reactor power and period stayed within prescribed limits. HSK required that the components of the renovated Reactor Protection System should fulfil "state of the art" requirements. HSK further demanded that a qualified surveillance for sufficient coolant flow through the core be included in the RPS, and that the RPS have qualified protection against fire, lightning and earthquake. In March 1992 the HSK limited the operating permit to December 31, 1993 – unless these requirements could be fulfilled.
- Improved physical protection of SAPHIR (BEW requirement).
  Since nuclear material is stored at SAPHIR which is classified by category I according to IAEA-INFCIRC 225, and since the resistance value of the institute fence has been downgraded with respect to safeguards, the pressure to upgrade the physical protection of SAPHIR increased. In particular, BEW insisted on the installation of entry locks for individual accounting and state of the art perimeter surveillance.
- Necessary improvement of the primary coolant loop.
  In support of the world-wide effort to reduce the nuclear proliferation threat, SAPHIR started to use fuel elements containing low enriched uranium (LEU) fuel instead of the previously used high enriched uranium. However, due to the higher power peaking factors of the LEU fuel, the design safety margin against insufficient cooling would then be reduced. Experiments and analyses to investigate the various aspects of the cooling of the core showed a number of limiting phenomena (stratification in the pool, limited degasification, uncertainty in the mass-flow measurement). In order to maintain a sufficient safety margin, including uncertainties, the power of the reactor was reduced to about 6 MW in August 1992.

A summary of the perceived deficiencies and the necessary shutdown-time for these improvements is given in Table 2.

– Reactor Protection System
– Physical Protection of Entrances (Safeguards)
– Improvement of Primary Circuit and Ion-Exchangers
→ Planned shutdown-time ~ 5 months

Table 2: Perceived deficiencies which (before 1992/93) were thought to need improvements.

4 SAPHIR Annexe

In order to eliminate the SAPHIR deficiencies, a retrofit program was planned. The main task was the construction of the RPS in an annexe building, thus providing the necessary protection (fire, lightning, earthquake) of the RPS itself. This would have allowed the construction and testing of the new RPS before decommissioning the old RPS, and a switch over to the new system would take place after thorough testing. This new annexe would also serve as a safeguarding-lock for the sensitive entry to the reactor hall.

The improvements of the primary coolant loop, (systems for adequate degasification and water cleanup), were planned for the basement of this annexe building.

This annexe building project was abandoned in January 1993 due to the rather high costs of about 5 million sFr. and in view of the short time span of planned operation until the end of 1996.

5 SAPHIR Retrofit

Because the plans for an annexe building were cancelled, the substance of the above-mentioned improvement program had to be planned and implemented within the confines of the existing SAPHIR building. An intensive concept evaluation, planning and negotiation process with the various responsible agencies occurred in 1993.

Significant achievements were accomplished:

- A revised concept for the RPS within these boundary conditions, including a safety analysis, was submitted to the HSK in March 1994. The retrofit concept describing all other improvements was presented in May 1994.
- In summer 1993 a new external and internal lightning protection system was designed and installed in- and outside the SAPHIR building.
- A proposal for adequate physical protection of the SAPHIR building, taking into account the fire escape requirements, which often conflict with safeguard requirements, was submitted to the agencies overlooking safeguards and conventional safety. Consensus has been reached, but approvals had not been received.
- The primary coolant loop improvements were installed and successfully tested (qualified and certified mass-flow measurements, degassing equipment, improved heating and stabilisation of the stratifying layer, etc.).
- The capability for 2 and 3 dimensional calculations of power distributions and thermohydraulic core analysis were acquired, enabling the reduction of uncertainties in the cooling conditions of the core.
- In June 1994 SAPHIR was about to receive the HSK approval of the RPS and the retrofit concept.

The original planning of the retrofit project envisaged a shutdown of about 5 months. The detailed planning however revealed that the necessary time for resolving the conflict between the fire escape and safeguard requirements was greatly underestimated. Furthermore, the installation of a qualified seismic protection system for the RPS in the old building proved to be more complex, more time-consuming (for approvals) and costlier than anticipated.

To summarize, PSI made an effort to retrofit SAPHIR. In view of the limited remaining operation time of about two years, before the definitive shutdown of SAPHIR at the end of 1996, PSI tried to minimise its investments in the retrofit by proposing adequate, but not generous, technical solutions. This, however, led to lengthy negotiations with the authorities. These difficulties are summarized in Table 3.

In May 1994 the shutdown was planned to last until February of 1995 but there was still uncertainty as to whether this period would be sufficient. Therefore, the PSI management decided to abandon its effort to retrofit SAPHIR for operation as a neutron source. PSI management asked those responsible for SAPHIR to make proposals for SAPHIR's future use as a low power reactor.

- – Physical protection of SAPHIR as part of a larger safeguard concept
- – Conventional safety (fire-escape, lightning)
- – Improved physical protection conflicts with fire protection
- – Nuclear qualified protection of the RPS with respect to
  - fire
  - seismic events
  - lightning
- – Quality assurance for all safety-relevant working steps
- – PSI attempts to realize the retrofit with minimal costs, leading to a
  - technically adequate solution and
  - large PSI self-production (soft- and hardware)
- → Lengthy negotiations with authorities to find consensus
- → Planned shutdown time increased to ~ 15 months

Table 3: Difficulties encountered in the planning of the retrofit program

6 Possible Option for SAPHIR-Utilization

Together with the decision of PSI not to continue operation of SAPHIR as a 10 MW neutron-source, it was decreed that, in the future, PSI will operate only one reactor, either SAPHIR or PROTEUS.

The three envisaged options for SAPHIR presented themselves, (somewhat simplified) as:

- Use of SAPHIR as a zero-power reactor for reactor physics experiments and a demonstration-reactor for schooling purposes. This would mean that the future reactor physics experiments at the PROTEUS would have to be performed at SAPHIR. Since PROTEUS, as zero-power facility, shows considerably more flexibility for reactor physics experiments, the PSI scientists preferred not to use SAPHIR as their only zero-power reactor.
- Use of SAPHIR as a fuel storage facility. At present there is a significant amount of fuel stored in SAPHIR; spent and fresh MTR fuel elements, special fuel from previous fuel projects, and minor amounts of fissile materials are present. If that fuel remains in SAPHIR, and it is difficult to imagine that it could be stored somewhere else, then SAPHIR becomes, by default, storage facility.
- Decommissioning of SAPHIR.

From these three options, PSI management chose, on July 14th, to decommission SAPHIR. The fuel shall be removed from PSI as soon as possible but shall remain in the SAPHIR pool until it can be transported away. Plans to dismantle the reactor shall be developed with the aim preparing the building for non-nuclear use.

7 SAPHIR and its Training Aspects

Since 1958 a total of 487 university students, 2210 engineering students and over 400 reactor operator trainees from the Swiss nuclear power plants have participated in reactor and radiation physics experiments and demonstrations at SAPHIR. Numerous PhD degrees were acquired in various fields such as neutron scattering, radiochemistry and materials research. The SAPHIR swimming pool concept and its facilities made the reactor an ideal training tool for demonstration and acquisition of "experience of the real thing".

These advantages became very obvious after the permanent shutdown of SAPHIR, when alternative solutions were needed. PSI's research reactor PROTEUS is not very well suited for fundamental training because its core is usually configured for the testing of experimental fuel designs. Alternative Swiss training reactors, with various drawbacks compared to SAPHIR, are CROCUS at the Federal Institute of Technology in Lausanne and a swimming pool reactor (AGN 211P) at the University of Basel.

Following the experience of a first training exercise with engineering students, the reactor at the University of Basel was found acceptable for fundamental training, although not fully equivalent to SAPHIR. CROCUS at Lausanne also offers possibilities, but with the geographical drawback of being situated at a greater distance from PSI.

8 Post Operational Activities

After the decision to shut SAPHIR down, an evaluation process started, taking into account the licensing situation, the operational state of the facility, the nuclear and the conventional safety situation and the personnel. It was decided to decommission SAPHIR in two phases:

- The consolidation phase-lasting about two years. During this period the reactor shall remain under the existing operating license, implying that the security surveillance will be maintained. The staff will be reduced since shift operation is no longer needed. During this consolidation phase the following tasks will be accomplished:
  - Measures (will be introduced) to improve the fire protection and other conventional safety hazards.
  - A technical and radiological surveillance system – to adequately protect the shutdown facility – will be implemented.
  - A strong effort will be made to remove all SAPHIR fuel, spent and fresh, from PSI.
  - A safety analysis report for the decommissioning will be written and submitted to HSK.
- The shutdown phase of the decommissioning will start when the safety analysis report has been approved by HSK and the spent fuel has been removed from the SAPHIR pool. During that period the activated and contaminated components will be removed and safely disposed of. At the end of this phase the SAPHIR reactor hall and the offices shall be available for unrestricted non-nuclear use.