I. The SIN Neutron Source, W. E. Fischer, SIN

1. General

During the year 1978, the idea of a spallation neutron source at SIN has been consolidated into an already fairly specified concept.[1] As a result of the symposium on applications of such neutron sources held at SIN (April 1978), we came to the conclusion that a continuous version exploits the capabilities of the SIN accelerator system optimally. Furthermore, this mode would provide for the users in Europe a complementary neutron source to the planned pulsed SNS device at the Rutherford Laboratory.

2. Physics of the Target

a. Neutron Yield

The average energy deposited by the cascade process as excitation energy in the nuclei of a lead target is roughly 100 MeV per nucleus. The primary proton energy is assumed to be 600 MeV. According to the thermodynamical nuclear model such an excited nucleus evaporates about eight neutrons. Including the contribution from spallation reactions of the second generation in the cascade inside a thick target, we obtain a source strength of about ten evaporation neutrons per incident proton. With a primary beam of 600-MeV protons with 1 mA beam current this corresponds to a source strength of 6×10^{16} n/s.

b. Energy Consideration

The beam power for a 1-mA, 600-MeV proton beam is 600 kW. By nuclear recoils and ionization the cascade-reaction deposits about 450 kW in the target with 125 kW being carried from the target by escaping cascade and evaporation neutrons. The missing 25 kW are used in breaking up the target nuclei - these cascade reactions being, contrary to nuclear fission, endothermal. These considerations, together with the yield discussed above, lead to a fairly low-energy deposition per useful neutron produced.

For a Pb/Bi target we have to deal with a heat deposition of 40 MeV/n - that is a value which is five times lower compared to neutron production in a nuclear reactor.

c. Activation of the Target

By the spallation reaction, about two to three protons with higher energy are knocked out of the target nucleus. The evaporation process of the residual excited nucleus is dominated by neutron emission. The target activation for a Pb/Bi target is therefore dominated by isotopes of Tℓ, Hg, Au, and evidently Pb and Bi. These isotopes are poor in neutrons and decay by β^+, γ-processes. The radiation from these heavy spallation products is relatively soft compared to the radiation from, e.g., fission products. A large part of the activation energy is therefore absorbed in the target itself. The correspondingly low radiation heating of material around the target region may present a significant advantage for the arrangement of a cold-neutron source in this area.

The saturation activity (β^+ and γ) with a 1 mA primary current is in the region of 1 MCi for a PB/Bi target. By self absorption, this activation leads to a heating power of about 6 kW. The long-term activation is given by the decay of ^{207}Bi with $t_{1/2}$ of ~ 38 yrs.

3. Neutron-Flux Distribution in the Moderator

Fig. I-I.1 shows a possible target/moderator arrangement. Due to the possibility of neutron multiplication by (n,2n) reactions of fast neutrons, as well as for technological reasons, the central part of the moderator around the target consists of Be. The best choice of the external reflector is D_2O due to its low absorption cross section for thermal neutrons. The results of a two-dimensional diffusion calculation with nine energy groups in this system are presented in Fig. I-I.2 and I-I.3. The primary proton beam current considered for this calculation is 1 mA. In the report[1] mentioned above, several modifications of this basic arrangement have been investigated.

4. Technology of the Target

The most attractive version of the concepts investigated consists of a Pb/Bi-eutectic circulated by an electromagnetic pump through a heat exchanger, giving off the heat to a secondary circuit. The main advantages of Pb and Bi for a target material are:

- low absorption cross section for fast and thermal neutrons
- low melting point of the eutectic (123 °C)

The window that is the wall between the eutectic and the vacuum of the proton beam line has to be cooled by heat transported to the liquid metal. The material of the window has to be chosen according to its thermal resistance.

a. Cooling Circuit

In order to obtain some insight into the problems of a Pb/Bi system, an order has been given to Innovent AG, Industrielle Forschung und Entwicklung, Zurich for a conceptual study of the treatment of the heat in a spallation source. According to this report[2] a circuit of the following type emerged (see Fig. I-I.4).

The Pb/Bi circuit including heat exchanger and pump is enclosed in a helium gas system. It provides on the one hand a security enclosure of the radioactive Pb/Bi, and on the other hand it serves as a pre-heating and liquification system for the eutectic. During operation, the Be mantle around the target can also be cooled with this helium gas. After shut down of the beam, the power from the activation of spallation products in the Pb/Bi may be removed by this helium system even in case of a drop of the circulation of the eutectic. The power in the helium system is low (10 to 20 kW) and corresponds to achievements of helium cooling well known at the institute in connection with cooling of special magnets and targets. Helium is relatively weakly activated and can be cooled with water from the tertiary circuit.

The heat exchanger will be cooled by "Dowtherm A" (freezing point 12 °C, boiling point 257 °C). Dowtherm A is an organic (but sufficiently radiation-resistive) liquid used in reactor circuits. As a circulation pump for the Pb/Bi circuit we consider an electromagnetic pump as the best, although most expensive, solution.

b. Target

Figure I-I.5 shows a schematic cut through a cylindrical Pb/Bi target including the Be mantle. The window at the entrance of the beam is made of Mo and optimally cooled by the entering Pb/Bi liquid. Two (pyrolytic graphite) windows with peripheral cooling sufficient for beam currents up to 3 mA have been foreseen upstream of the Mo window. These graphite windows permit a diagnostic during operation (concerning leaks in the main window) by continuous observation (mass spectrometer) of the gas composite between the windows. The disposition is coaxial in order to minimize the thermal stress. The whole system, including the Be part of the reflector forms a compact cylinder, which may easily be exchanged.

c. Layout

For reasons of simplicity and costs we consider a horizontal proton beam line, 1.5 m above ground. Similar arguments lead us to horizontal neutron beam lines, about 30 cm above or below the source in order to reduce the background of direct radiation and fast neutrons from the source. A schematic layout is shown in Fig. I-I.6.

References

1. W. E. Fischer, W. Joho, Ch. Tschalar (SIN); B. Sigg (IRT-ETH); H. Rauch (Atominstitut der Oesterreichischen Hochschulen, Wien), "Studie uber eine Kontinuierliche Spallations-Neutronenquelle am SIN."

2. H. P. Weiss, Innovent AG, Zurich, "Warmehaushalt einer Spallations-Neutronenquelle."

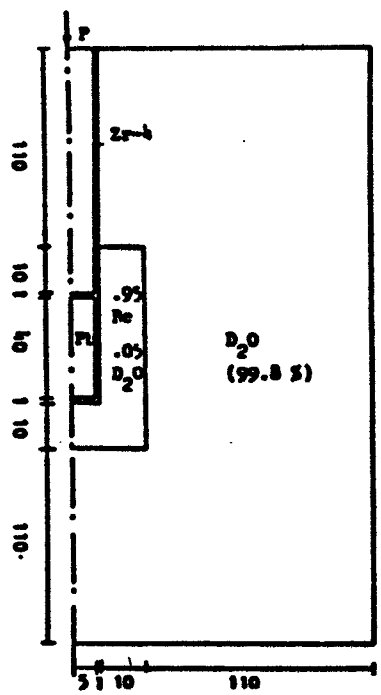

Fig. I-I.1. Geometry of the target/ moderator system.

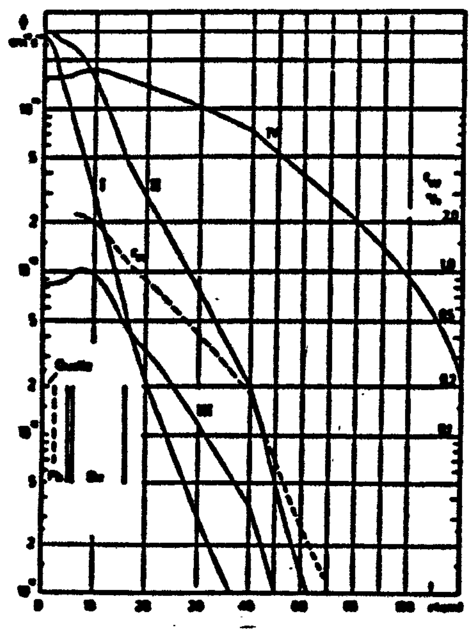

Fig. I-I.2. Radial distribution of the group fluxes and the Westcott-Coefficient.

I: 0.86 MeV $\leq$ E $\leq$ 10 MeV
II: 1.5 eV $\leq$ E $\leq$ 0.86 MeV
III: 0.14 eV $\leq$ E $\leq$ 1.5 eV
IV: E $\leq$ 0.14 eV (thermal)

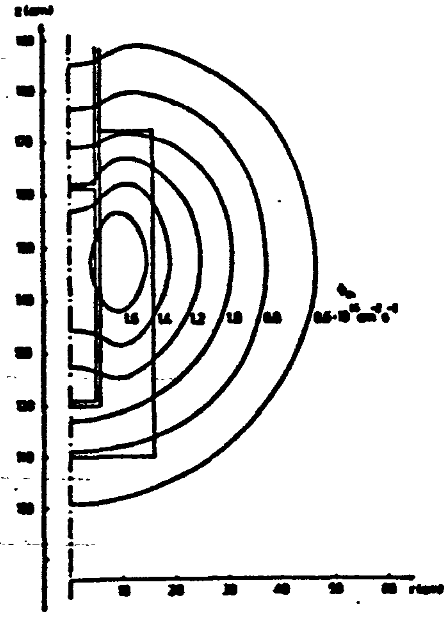

Fig. I-I.3. Flux lines for constant thermal neutron flux.

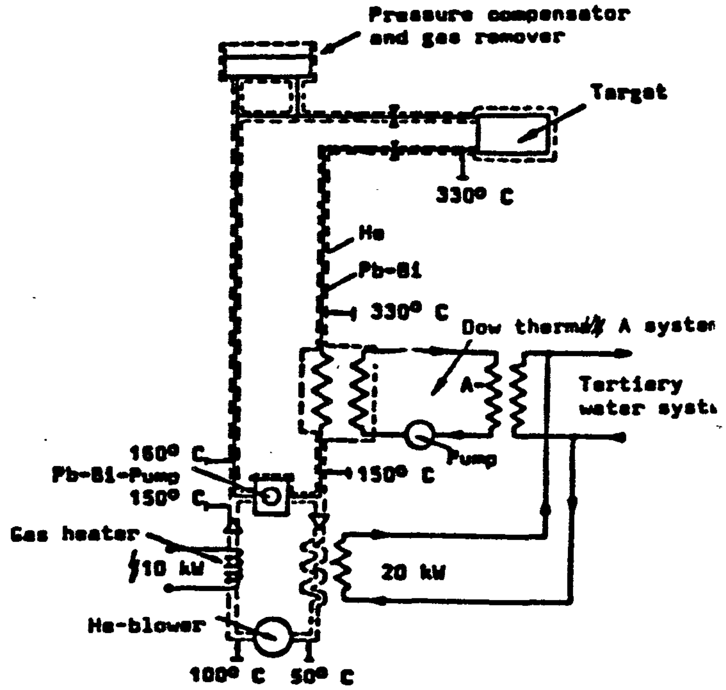

Fig. I-I.4. System of cooling circuits for a Pb/Bi target.

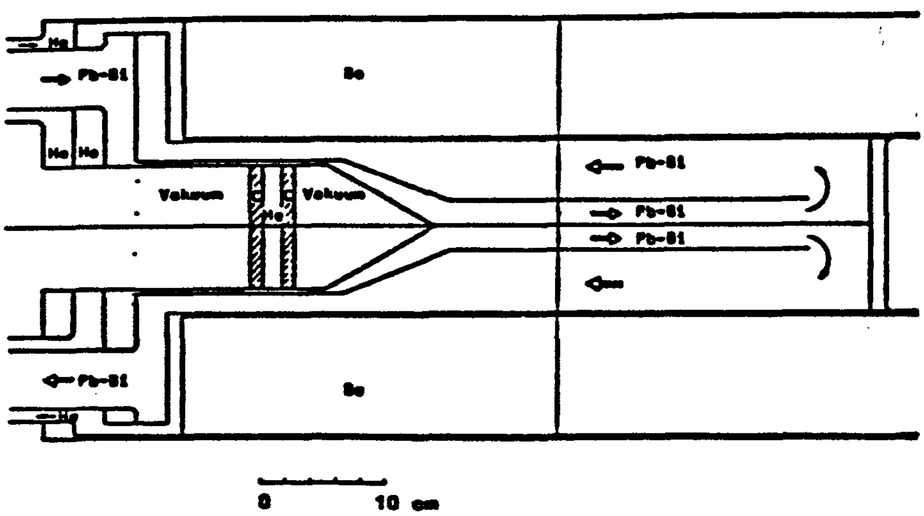

Fig. I-I.5. Section through a Pb/Bi target.

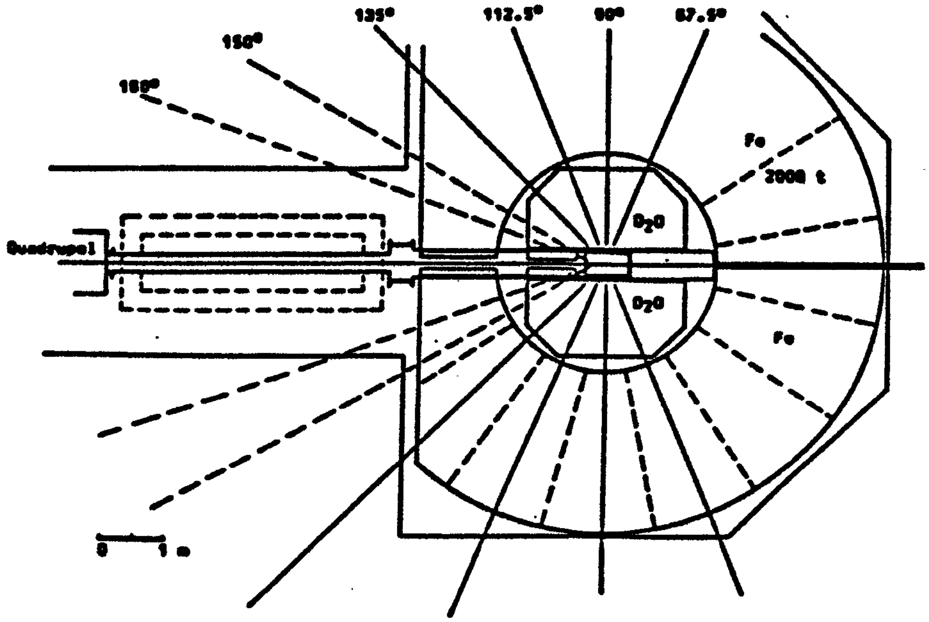

Fig. I-I.6. Schematic layout of the spallation neutron source.

J. An Intense Spallation Neutron Source for West Germany,

J. E. Vetter, KFK Karlsruhe

1. Background

The first generation of research reactors, the neutron sources of today in West Germany, will soon reach an age where significant modifications will be needed to maintain safe and reliable operation. Because of this situation and an increasing demand for irradiation capacity, a modern powerful neutron source in West Germany has been discussed. In 1977 the "MFR Ad Hoc Committee" was appointed by the Minister of Science and Technology to discuss a neutron-source project, which at that time was conceived to be a medium-flux reactor (MFR). The MFR conceptual design, as proposed, is still a viable option and is regarded as an alternative to a spallation neutron source, which was recently recommended by the panel as the most promising concept.

This recommendation was preceded by a discussion with a subgroup which studied various machine concepts under the following assumptions:

- The source should deliver a time-average thermal neutron flux of 6×10^{14} n/cm^2·s, called 'basic machine' in the remainder of this discussion.
- The new source should present the option to increase the neutron flux to a substantially higher value.