An Overview of the Planned Advanced Neutron Source Facility

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Abstract: The Advanced Neutron Source (ANS), now in the conceptual design stage, will be a new user facility for neutron research, including neutron beam experiments, materials irradiation testing and materials analysis capabilities, and production facilities for transuranic and lighter isotopes. The neutron source is to be the world's highest flux beam reactor and is based on existing reactor technology to minimize safety issues. The preferred fuel, U_3Si_2 , has been tested in operating reactors in the United States, Japan, and Europe. The core is cooled, moderated, and reflected by heavy water, common practice for research reactors.

1. Introduction

The Advanced Neutron Source (ANS) facility is based on a 350 MW heavy-water research reactor with a thermal neutron flux approaching $10^{20} \text{ m}^{-2}\cdot\text{s}^{-1}$. It will be a user facility allowing more than 1,000 industrial, academic, and government researchers to perform experiments each year. The ANS will be the U.S. Department of Energy's (DOE's) principal new neutron research facility for science and technology and will replace the High Flux Isotope Reactor (HFIR) at Oak Ridge as the Western world's only source of transuranium isotopes. All of this is reflected in the project's technical objectives (table 1).

The performance goals for the facility are set with the help of a National Steering Committee for an Advanced Neutron Source (NSCANS), a group of more than 30 people representing all the fields of science and all the organizations expected to use the new facility. Table 2 shows the quantitative performance goals. In some cases, the requirements of the different user groups conflict—for example, a heavy loading of transuranic isotopes can reduce the peak thermal neutron flux available at the beam tubes—and the NSCANS helps to balance and prioritize those different requirements.

The schedule originally proposed for the project [1] has been extended several times by funding limitations. The most

aggressive schedule starting from our present position (fig. 1) would lead to startup of the reactor in 1999. The associated funding profile is shown in fig. 2.

2. ANS Reactor Technology

To meet the scientific needs of the neutron scattering community, the reactor should be designed so that the peak thermal neutron flux is found outside the core in a region that is accessible to beam tubes and that is large enough to accommodate cold and hot neutron sources. To achieve this, a small, undermoderated core must be employed (so that few neutrons thermalize inside the core region) surrounded by a large reflector of low absorption material in which the fast neutrons escaping from the core are moderated. In addition, the higher the fission power, the more neutrons will be produced.

The high-power density requires particular attention to thermal hydraulics, fuel performance, and other safety questions. One example of this attention is the development, in the very earliest (preconceptual) stages of design, of a probabilistic risk assessment (PRA). The PRA results have already influenced the design concepts, especially of the cooling system. In addition, several inherent aspects of the ANS reactor contribute desirable safety features: the relatively low power level and fission product inventory (< 10% of a typical

power reactor), the large containment dome needed to house experiments around the reactor, the decision to keep the cooling water below the normal boiling point, and the choice of upflow coolant direction in the core.

The combination of a small core and high power demands a fuel geometry that puts a large cooling surface in a small volume, and a high-density fuel form that puts a critical mass of ^{235}U in a small volume.

To minimize technical risk and safety issues, the project has also adopted a requirement that we should not rely on new or unproven inventions to achieve the minimum performance criteria. This approach leads to a design with many similarities to the HFIR, but with a higher power, higher coolant velocity, and enriched uranium silicide (U_3Si_2) fuel [2, 3].

Other differences from HFIR include more passive safety features, containment instead of confinement, heavy water instead of beryllium as the reflector material, large experimental areas, two cold sources, a hot source and many beam lines (25 vs 4 at HFIR).

The project has devised an improved research reactor core design, with two annular fuel elements of different diameter (fig. 3). These fuel elements are assembled from involute-shaped plates of aluminum clad cermet fuel, similar to the elements used in

the Institut Laue Langevin (ILL) reactor at Grenoble and in the HFIR.

Two separate, diverse, fast shutdown systems are incorporated. One, also used for control, is inside the core, and the other is outside the primary coolant system in the reflector tank (fig. 4). Either system alone can safely shut down the reactor, even with one rod stuck. The core assembly, which has space for transuranium production rods and irradiation capsules for materials testing, is surrounded by the 0.5-m-diam core pressure boundary tube (CPBT) which, containing the high-pressure heavy-water coolant, is analogous to the giant pressure vessel of a power reactor. The CPBT passes through the middle of the low-pressure heavy-water reflector tank that provides space and mechanical support for the beam tubes, rabbit tubes, cold and hot sources, and neutron guides (fig. 5). The facility includes a four-building complex designed and constructed to separate more secure areas from the experimental spaces accessible to users (fig. 6).

3. Nuclear Safety

Despite its high-power density, the ANS reactor has certain inherent safety advantages over power reactors (table 3), and the project is planned and scheduled to maximize them. One aspect of this is the use of PRA, even in the preconceptual design

phase, to identify key safety issues and components and to evaluate alternative design concepts.

This approach has resulted in many passive or inherent safety features in the reactor cooling system (fig. 7). The design emphasizes natural circulation for emergency heat removal, diverse heat sinks (inside and outside containment), passive pressure control by gas-pressurized accumulators for the early phases of any pipe-break event, and passive coolant inventory control (by installing equipment in submerged or floodable cells) for loss-of-coolant events.

The ANS will meet the DOE safety policy for nuclear facilities and will have fully documented preliminary and final safety analysis reports and an environmental impact statement. The safety case will address, besides the usual reactor issues, unusual circumstances arising from the high-power density and the liquid deuterium cold sources.

4. Experimental Facilities

Two liquid deuterium cold sources are planned. The design concept is based on the ILL vertical cold source. However, the higher power level of the ANS reactor will lead to much higher gamma and neutronic heating rates. Therefore, we plan to cool the LD₂ cryostats by a separate stream of cold helium gas pumped through tubes in close

contact with the cryostat walls. Only the heat deposited directly in the LD₂ will be removed by allowing the cold moderator to boil, the resulting vapor being condensed in helium-cooled condensers above the reflector tank and the liquid deuterium returning by gravity to the cryostat (fig. 8). In this way, the cold sources can be placed in a region where the unperturbed thermal neutron flux is about five times that at the ILL cold source, but the heat to be removed by LD₂ boiling is about the same because in the ILL cold source the walls are also cooled by boiling heat removal.

The two cold sources will feed a total of 14 neutron guides leading into a very large experimental area. There is space for about 30 instruments in the guide hall (fig. 9), although we recognize that developments in instrumentation and shifts in scientific priority will change the layout presently planned.

There is space on both the first and second floors of the large (60-m-diam) containment dome for hot, thermal, and very cold neutron beams and experiments. We would like to place the hot source on the outside of the reflector tank to minimize its influence on the reactor core and on safety issues. However, lack of funding has meant that almost no work has been done on the hot-source design.

Besides the beam facilities, there are rabbit tubes for materials analysis, materials irradiation facilities, and isotope production

facilities. Proposals have been made, but not yet studied in detail, for a positron source, for medical therapy irradiation facilities, and for various other capabilities. With the aid of the National Steering Committee and the scientific community, these proposals will be carefully explored.

5. Summary

A reactor design based on previously developed technology can meet the performance criteria set by the user community for a new Advanced Neutron Source facility to meet the needs for improved experimental capabilities in all areas of neutron research.

The source of neutrons will be a high-powered research reactor with many inherent and advanced safety features.

A large complement of experiments is planned, including very many cold, thermal, and hot neutron beams, as well as multiple irradiation facilities.

Table 1. Advanced Neutron Source Project technical objectives

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- To design and construct the world's highest flux research reactor for neutron scattering
- 5 to 10 times the flux of the best existing facilities
 - To provide isotope production facilities that are as good as, or better than, the High Flux Isotope Reactor (HFIR)
 - To provide materials irradiation facilities that are as good as, or better than, the HFIR.
-

Table 2. Major design criteria for the ANS reactor

Parameter	Minimum Criteria
Peak thermal flux ^a in reflector	≥ 7.5
thermal/fast ratio	≥ 80.0
Thermal flux at cold source position	≥ 2.0
Epithermal flux for transuranium production	≥ 0.6
epithermal/thermal ratio	≥ 0.25
Thermal flux for isotope production	≥ 1.7
Fast flux for small materials tests	≥ 1.4
fast/thermal ratio	≥ 0.5
Fast flux for larger tests	≥ 0.5
fast/thermal ratio	≥ 0.3

^aAll fluxes in units of 10^{19} neutrons $\text{m}^{-2} \cdot \text{s}^{-1}$

Table 3. Several features of the ANS research reactor offer inherent safety advantages over power reactors

Feature	Comment
Lower thermal power level	~ 300 MW compared with ~ 3000 MW means less stored and circulating energy
Lower fission product inventory	~ 6 kg compared with ~ 100 kg means much lower source term
Lower coolant temperature	~ 90°C compared with ~ 325°C, so that coolant water would not flush into steam during a pressure loss
High degree of containment	Containment as big as a typical power reactor (to provide space for neutron beam experiments), but 10 times lower power level
Large U.S. DOE site at Oak Ridge	Located further from the site boundaries than some much larger power reactors

FIGURE CAPTIONS

Fig. 1 Overall schedule proposed for the project.

Fig. 2. Funding profile

Fig. 3. Comparison of HFIR, ILL, and ANS core designs.

Fig. 4. ANS reactor core and control systems.

Fig. 5. Reflector tank assembly.

Fig. 6. Overall view of facilities.

Fig. 7. Some safety features of the ANS reactor and cooling systems.

Fig. 8. Cold source assemblies.

Fig. 9. Guide hall and instrument space.

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ADVANCED NEUTRON SOURCE

FJP
11/5/90

FY-94 LINE ITEM

KEY DECISION POINTS

LINE ITEM FUNDS

OPERATING FUNDS

Advanced Neutron Source Funding Distribution

The ANS Reactor Core Design Combines The Best Features Of Earlier Designs

ANS REACTOR SYSTEMS

PERSPECTIVE OF ANS FACILITY

FIG. 8

Cold water in summer blues

to id ripe, due to
prolonged stay in room
to spring 11-26

11/01/90
RMB
EXP-GH-B

END

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