CONCEPTUAL DESIGN OF THE TARGET STATIONS OF THE IPNS UPGRADE

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Abstract

The IPNS Upgrade is a new Pulsed Spallation Neutron Source based on a nominal 1 MW proton beam. The accelerator system delivers 0.5 mA of 2.2 GeV protons in 0.3 μsec pulses at 30 Hz. Two target stations receive the pulses, one at 10 Hz, the other at 30 Hz with every third pulse missing. Protons impinge horizontally on the targets. The targets in each target station are identical for the purposes of this reference design, and consist of Tantalum-Tungsten alloy plates in a split target (flux trap) arrangement, each section separately cooled by normal water. The high frequency target and associated moderators can accept the full 1 MW beam power. Each target supports six moderators, two at the front, two at the back and two vertically extended moderators in the flux traps. Three beams are led from one surface of each moderator, providing eighteen beams lines in each target station, diverging 13 ° from each other. The moderators are separately optimized to fit the needs of the scattering instruments, and are of circulating water, liquid methane and liquid Hydrogen, reflected by Beryllium and/or heavy material, decoupled or coupled as meets the instrument requirements. Extensive use of premoderators and composite moderators maintains low levels of heating and radiation damage in the moderators. Both target stations are equipped with hot cells for servicing the target-moderator-reflector systems, and both contain irradiation tubes for use in neutron activation and radiation damage applications.

The target stations are located in existing large experiment halls, which will require little modification. Columns extending to bedrock support the massive shields. Space is available to accommodate secondary applications such as pulsed muon facilities.

This paper describes the design of the new facilities and some of the pertinent engineering analysis.

Introduction: Considerations Underlying the Design

Discussions held during its meetings in September, 1992, led the DOE Basic Energy Sciences Advisory Committee's Panel on Neutron Sources(1), chaired by W. Kohn, to recommend "development of competitive proposals for the cost effective design and construction of a 1 MW pulsed spallation [neutron] source." The recommendation was based on the understanding that such a source would be feasible to construct with present day technology, and would represent a highly effective complement to the Advanced Neutron Source, which the Panel recommended as its first priority to "complete ... according to the schedule proposed by the project." The IPNS Upgrade is Argonne's response to the pulsed source recommendation. Our feasibility study has taken place over about the last six months, funded by Argonne National Laboratory, and reached the stage of preliminary documentation.

The IPNS Upgrade is to be installed in existing buildings in the former ZGS accelerator complex at Argonne. Preliminary calculations indicate that total neutron yields are nearly proportional to the proton energy, while power and neutron production densities are only mild functions of the proton energy. Figure 1 shows the total neutron yield calculated for 10 cm diameter Tantalum targets. Figure 2 shows the power density, emerging fast neutron current and total power in the target. These observations essentially freed accelerator designers to choose their own proton energy. The paper of Jerng elsewhere in these proceedings describes further calculations.

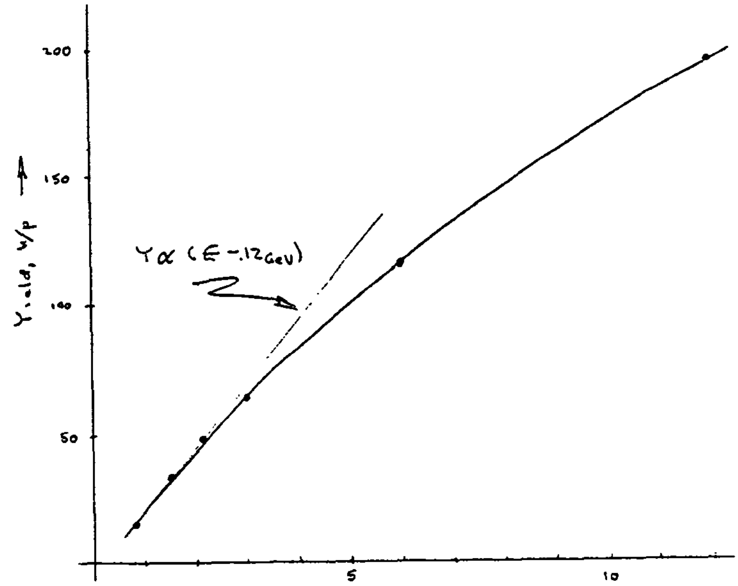

Figure 1 Neutron yield for 10-cm diameter Tantalum targets 100 cm (200 for higher energies) long, as a function of proton energy.

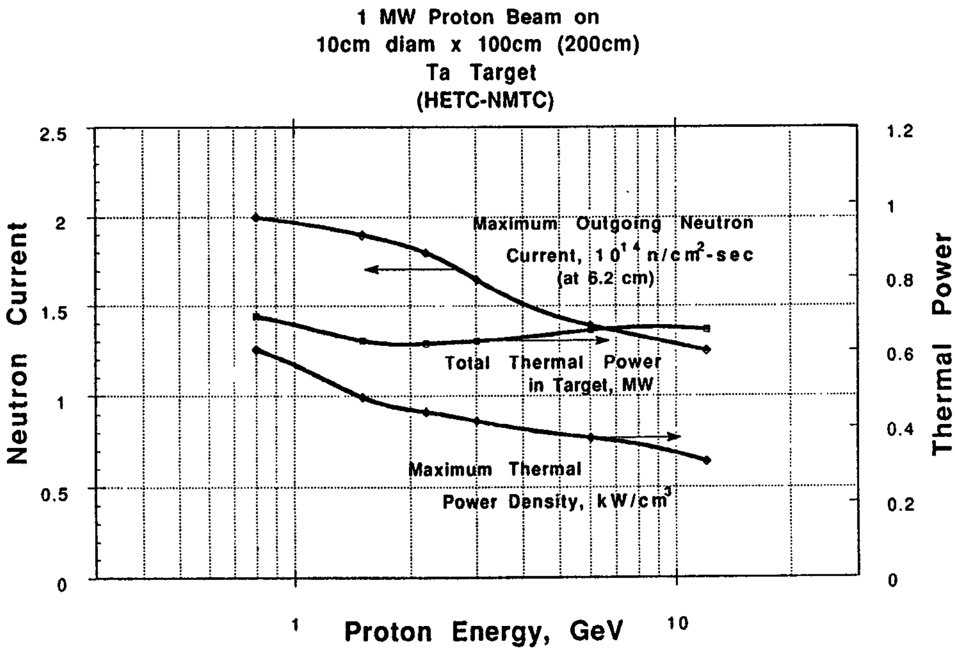

Figure 2 Maximum outgoing fast neutron current, total thermal power and maximum power density in Tantalum targets.

A survey, compiled for reference, of neutron scattering instruments appropriate for a 1 MW source provided important guidance. There must be provision for about forty instruments. There are two roughly-equally-populated classes of instruments, ones for which 30 Hz pulsing is appropriate, and those for which 10 Hz is required. These considerations led to the conclusion that two target stations are needed, one operating at 10 Hz, the other normally receiving the remainder of a 30 Hz pulse train. Each target station must provide about twenty beams. The paper of Crawford, elsewhere in these proceedings further describes the reference instrument complement. The study also indicated moderator and flight path requirements.

Preliminary considerations of vertical proton beam geometry led us to adopt horizontal proton beam geometry in view of the greater expense and difficulty of providing the large 90° bends implied by the vertical arrangement, and because the required number of beams can be provided by targets with horizontal proton beams.

The realization that targets, moderators and other components near the targets will have finite lifetimes and require convenient replacement and alteration, led us to incorporate a fully-equipped hot cell with each target station.

Opportunity to use the existing ring building and shield of the former 12 GeV Zero Gradient Synchrotron led us to choose 2.2 GeV proton energy, the highest energy machine for which the space is adequate in view of the needs for straight section space dictated by the 1 MW power requirement. The paper of Cho elsewhere in these proceedings further describes the accelerator system. Figure 3 shows the layout of the IPNS Upgrade. The design proceeded on the basis of these established fundamental parameters.

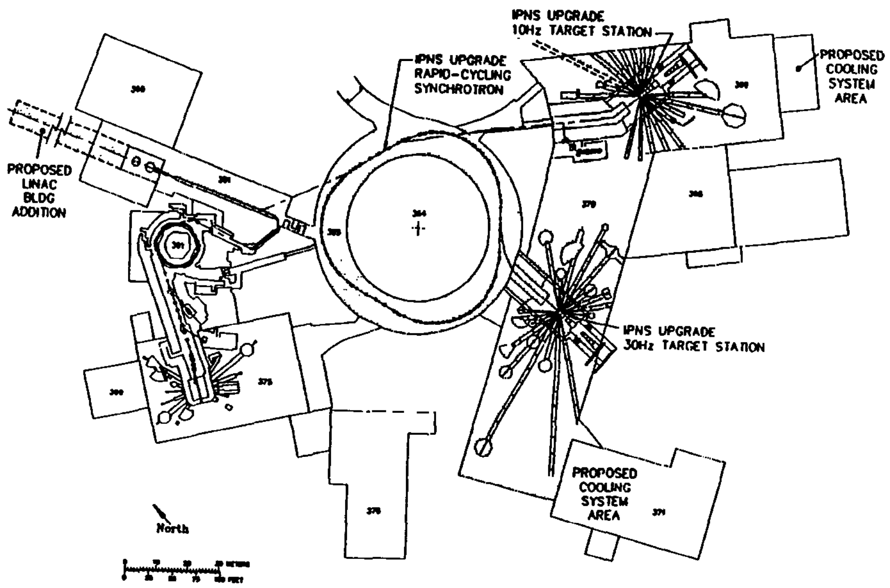

Figure 3 Layout of the IPNS Upgrade. The existing IPNS is in the lower corner of the drawing.

Details of the Target Station Design

We adopted the split target design for our targets, with six independently-optimizable moderators. At this level of description, the two target stations are identical. Figure 4 shows the target and moderator arrangement. Each moderator has one viewed surface that provides three beams. Nine beams emerge from each side; neighboring beams diverge 13°.

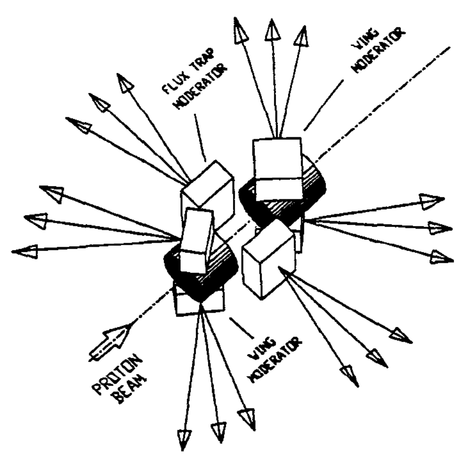

Figure 4 Split target with six moderators; flux trap moderators are 20 cm tall.

Designs of targets and moderators provide for simple servicing. Figure 5 shows the target and moderator assembly.

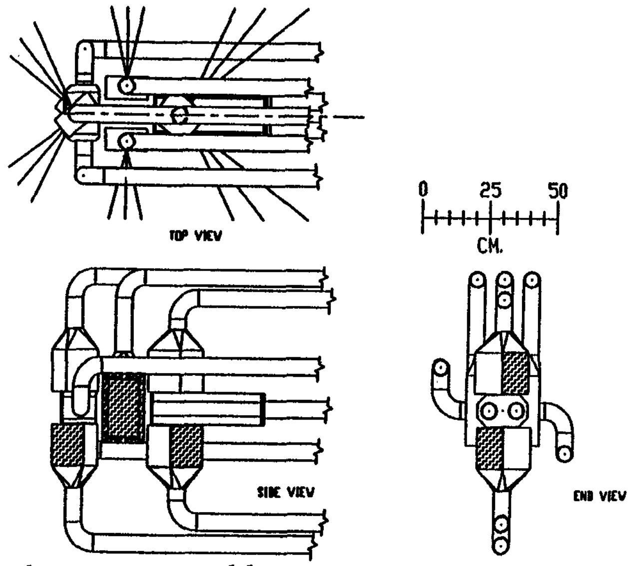

Figure 5 Target and moderator assembly

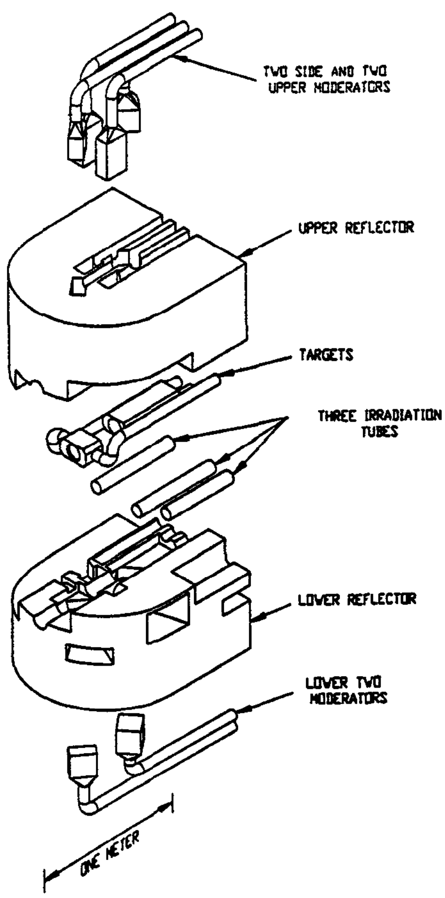

Figure 6 Exploded view of the target-moderator-reflector assembly

Figure 6 shows an exploded view of the target-moderator-reflector assembly. These, with an outer iron shield block, form a "train", which moves as a unit. Three irradiation tubes provide access for neutron activation and neutron radiation effects experiments. Samples can be inserted and withdrawn from remote locations within and outside the remote handling facility. Components fit together in such a way that when the target train is retracted into the servicing cell, each part in order can be lifted free with minimal interference.

All components nearby the target require active cooling, which is provided by separate water streams. During operation, the target train rests inside a sealed, Helium-filled volume defined by a stationary liner inside the shield. Neutron beams pass through thin window sections in the Aluminum target tank. The target is triply enclosed. The outer end of the target train carries a seal sheet which can be disengaged to enable the many plumbing connections to be made and unmade and allows the train to be moved into the servicing cell. The main biological shield consists of an inner iron core and an outer layer of concrete a total of 6.5 m thick in the shortest (90°) direction. The 15,000 ton shield rests on a reinforced concrete pad supported by columns extending about 90 ft down to bedrock. Figure 7 shows the target station and hot cell with the target train in the servicing position.

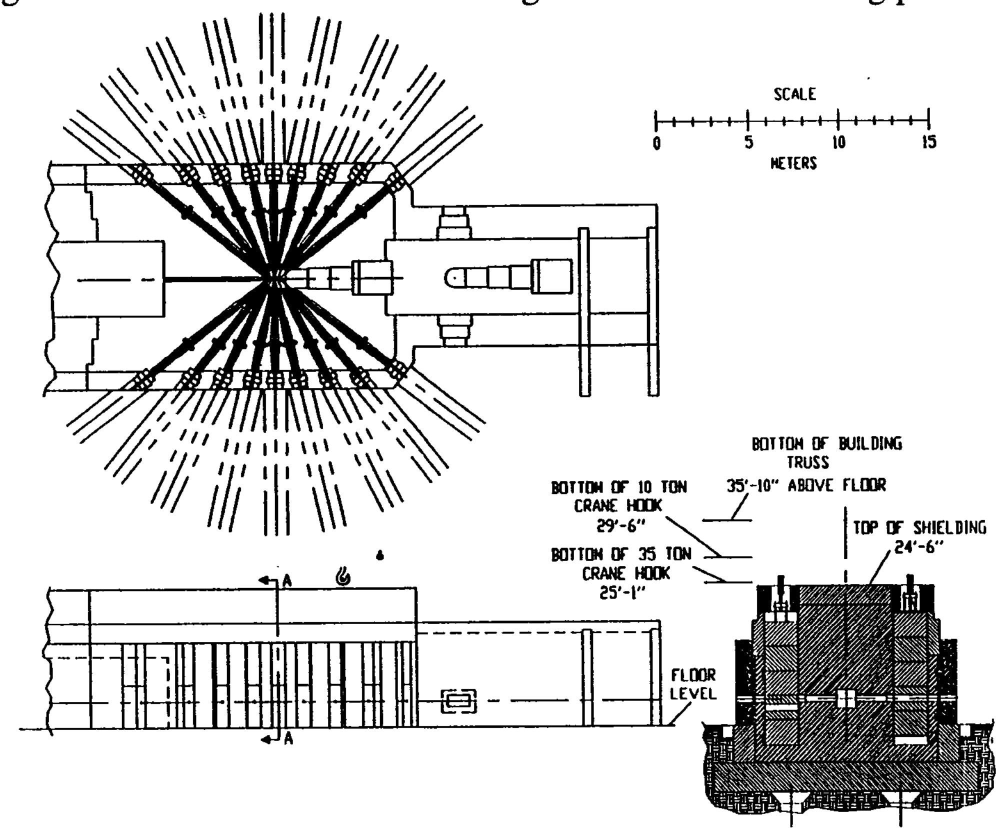

Figure 7 Target station and servicing cell

Neutron beams pass through ports which contain collimating or neutron guide elements. Gates, Figure 8, of steel and other material of high shielding effectiveness, 2 m thick, provide for hands-on changing of samples during operation. Gates have fine adjustment mechanisms to enable close alignment of collimating and guide sections as required.

Figure 9 shows the two target stations as they will be located in existing experiment halls adjacent to the accelerator.

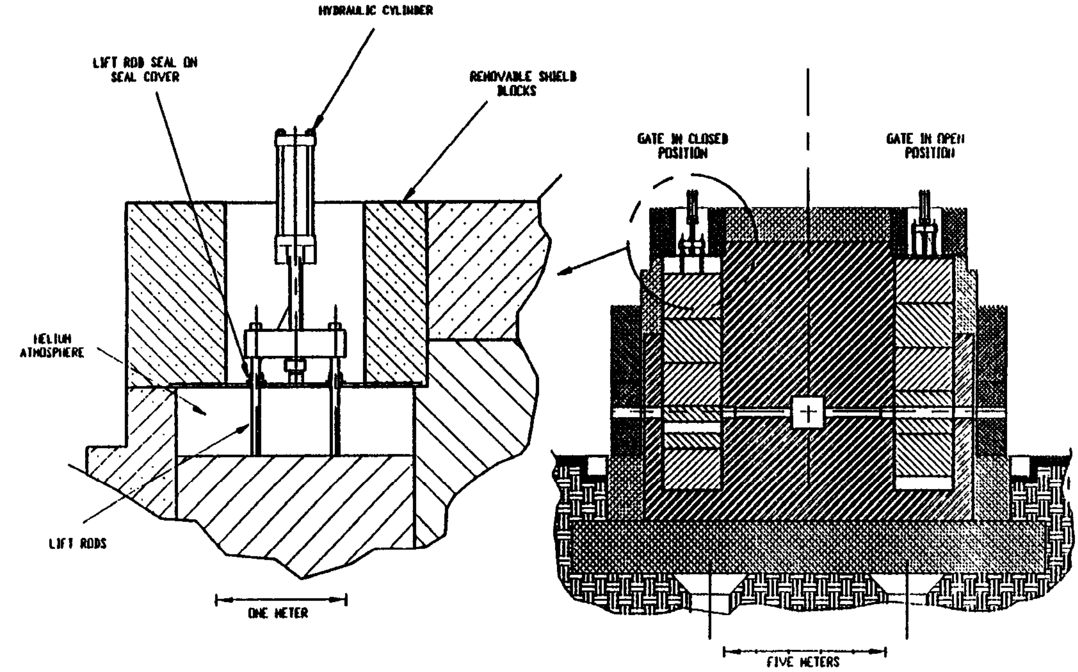

Figure 8 Beam gate and drive mechanism

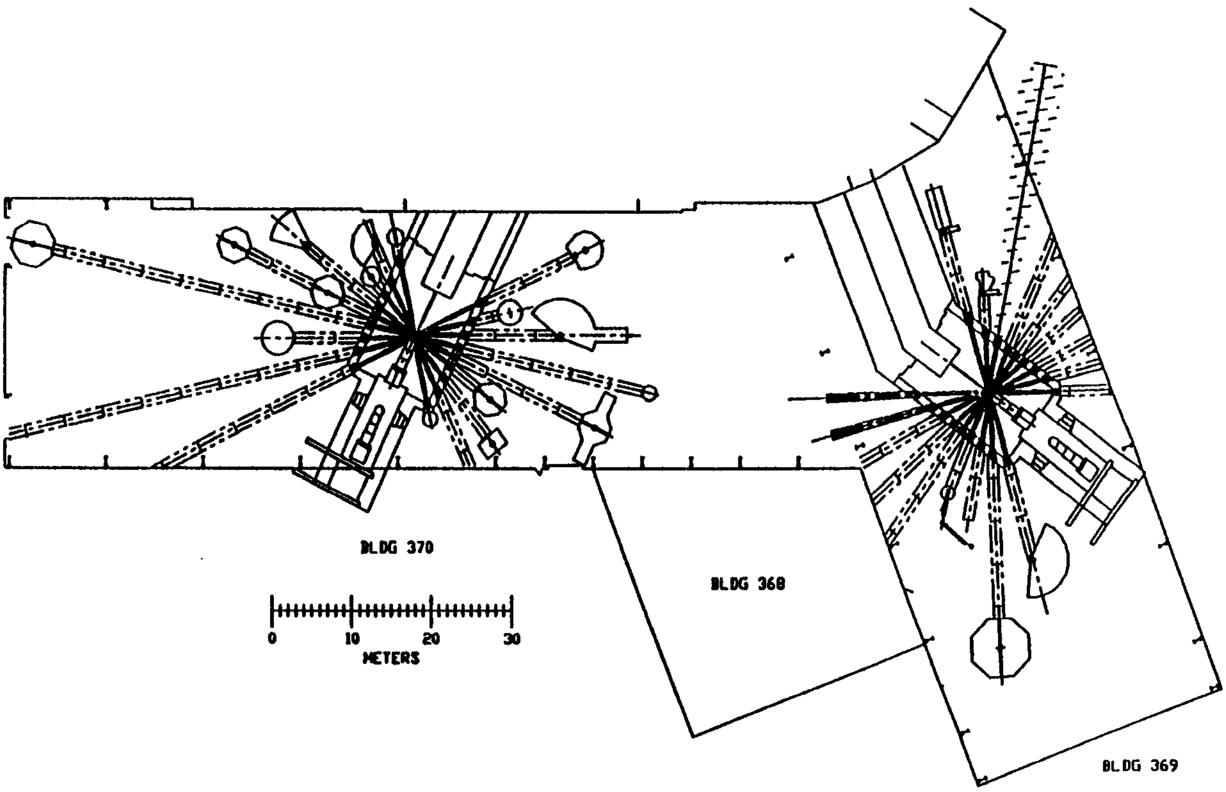

Figure 9 The high frequency and low frequency target stations

Targets

Preliminary considerations of neutron yield, density, structural properties and corrosion resistance led us to choose a Tantalum metal, water cooled target. Figure 10 shows three views of the split target arrangement. The target plates are roughly elliptical in shape.

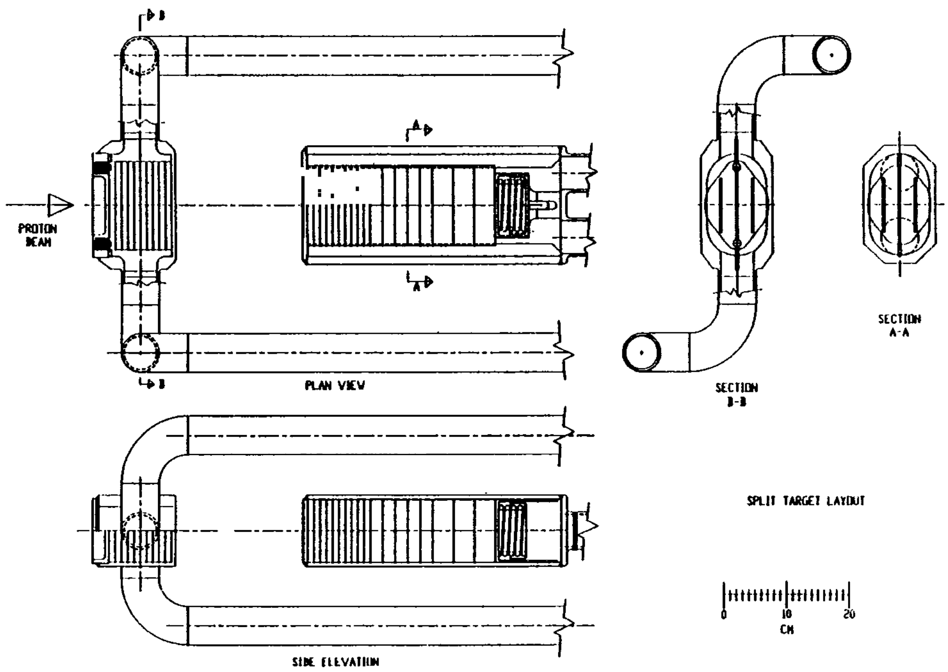

Figure 10 Three views of the front and back sections of the target

Each target half is cooled by a separate system with all the usual components. HETC-NMTC power density calculations for a 2.5 cm-radius at half-maximum, Gaussian, 2.2 GeV proton current distribution, truncated at 5 cm radius, formed the basis for thermal hydraulic analysis. The design provides that the target can accept the full 1-MW, 30 Hz beam. Water flow velocity is about 5 m/sec; coolant channel gaps are 1.6 mm. In the front target, the surface heat flux determines the disk thickness on the basis of avoiding local boiling. In the back target, disk thicknesses are determined by a criterion on maximum center temperature. Figure 11 shows the disk center surface temperatures and interior disk center temperatures as functions of the distance into the target.

Thermal stress calculations indicate that for the conditions of this analysis, Tantalum metal has inadequate yield strength. However, Tantalum-10%Tungsten, a commercial alloy, has much higher strength and comparable properties otherwise, and is our choice for this reference target design.

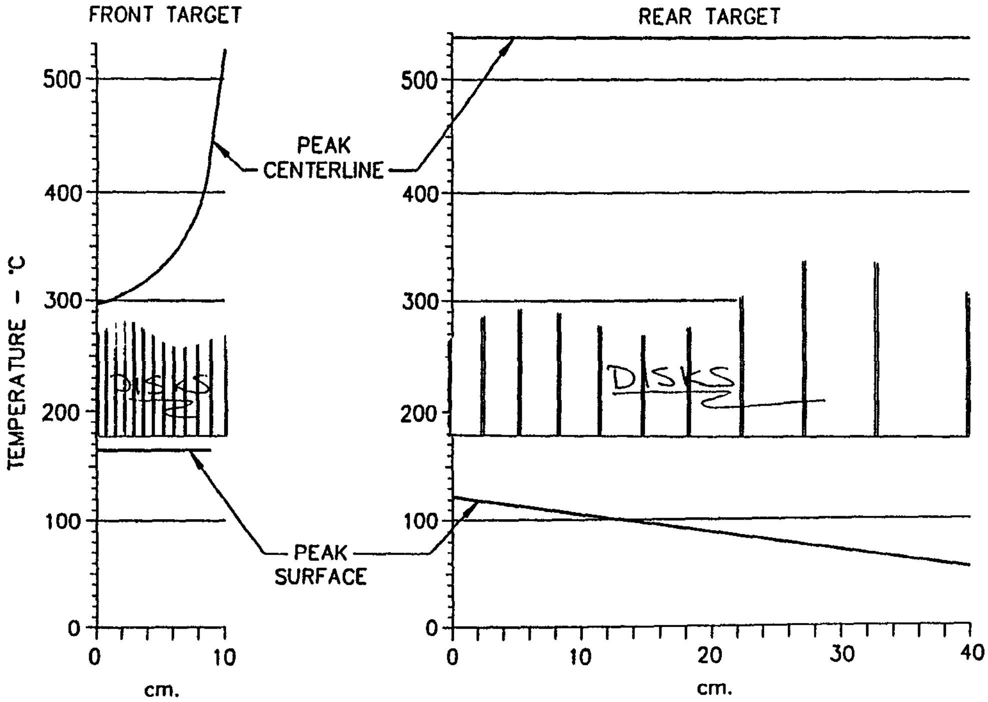

Figure 11 Disk surface center and disk interior center temperatures

A survey of metallurgical data relevant to candidate target materials uncovered information on hydride embrittlement of various Tantalum and Tungsten alloys, Figure 12. In the corrosion tests cited, samples were exposed to concentrated

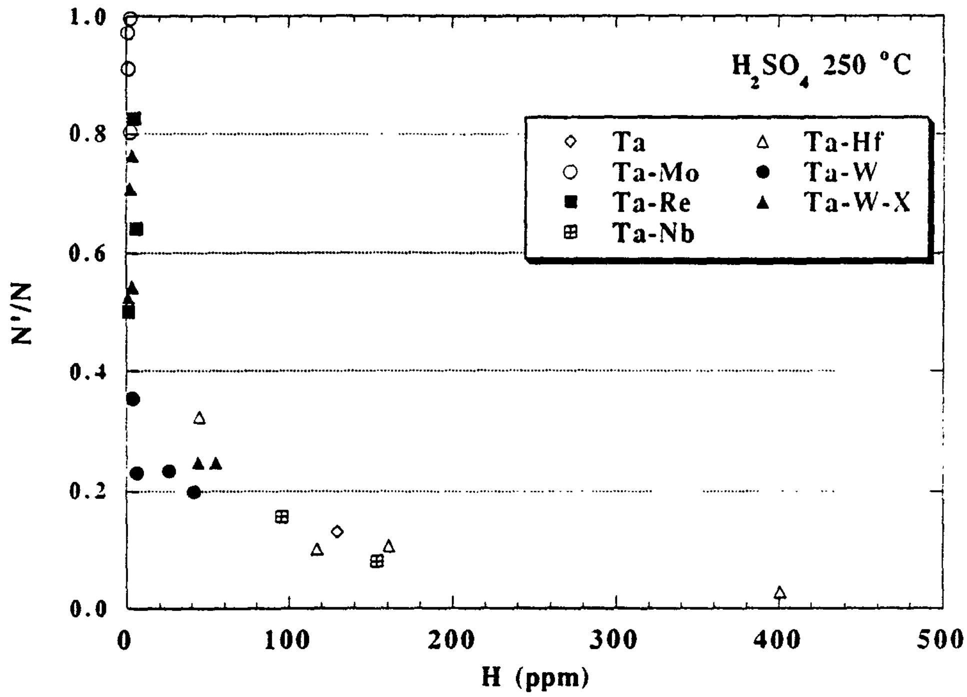

Figure 12 Ratio of the number of stress cycles to failure of hydrided Tantalum alloys

sulfuric acid, then subjected to cyclic mechanical stress. The figure shows the ratio of the number of cycles to failure of the corroded specimens to the number of cycles for uncorroded materials, and relates the reduction in cyclic stress tolerance to the measured concentration of Hydrogen introduced due to corrosion. Hydrogen concentrations at the level of 100 ppm appear to produce very significant reductions in cyclic stress tolerance, moreover such concentrations can readily be imagined to develop in rather short times in targets irradiated by proton beams of the contemplated current density. Two issues arise from these observations, namely, the significance of the indicated reduction in stress tolerance and the actual rate of Hydrogen buildup. The latter question requires calculation and perhaps measurement, since, on the one hand, most of the incoming protons react in nuclear reactions and disappear, while on the other, secondary protons are produced in spallation reactions. This is one of the more significant R&D questions uncovered in the course of our feasibility study.

Conclusion

We have produced a feasible design for a neutron source with two target station, subject to favorable answers to only a few R&D questions. Exclusive of the cost of supporting research, the Total Estimated Cost for the two stations is approximately $60 M. Cost and schedule estimates, and the list and cost of needed Research and Development efforts are being refined.

References

1. W. Kohn, "Neutron Sources for America's Future", Report of the Basic Energy Sciences Advisory Committee Panel on Neutron Sources, January, 1993.