Tests are to be made to gather flow/pressure drop profiles for each of the channels within the target vessel.

4. Monitoring and Control

a. Flow/Pressure Drop Profile

The flow/pressure drop characteristic mentioned above will be used as the main indicator for uranium target-plate swelling in the operational target.

b. "Burn-Out" Warning

The overheating of any target plate will be sensed using noise monitoring. The onset of film boiling leading to "burn out" is accompanied by considerable vibrational noise (the steaming bottle effect) which will be monitored and the signal used to control flow and/or shut off the proton beam.

c. Target Parameters

The target parameters are as follows:

- peak-power density, 940 watts/cm^3
- peak-heat flux, 304 watts/cm^2
- water velocity, 3.2 metres/sec (10 ft/sec)
- water temperature, 38 °C
- pressure drop through plate gap, 0.05 bars (0.75 psi)
- thickness of peak-target plate, 6.5 mm of uranium, 0.25 mm of zircaloy cladding.

F. IPNS-I Target-Station Design and Engineering, J. R. Ball, ANL

The IPNS-I target stations are designed to meet the experimental program goals to the maximum extent possible. The IPNS-I facility consists of two experimental assemblies, one for neutron-scattering research and one for radiation-damage research. It is anticipated that the targets for these two assemblies will be of identical design. However, flux and spectrum measurements are currently being made on IPNS-I mockup assemblies at the ZING-P' facility to determine the most suitable target material for the radiation-effects facility. This summary will describe the design and engineering of the IPNS-I uranium target assembly and the neutron-scattering experimental assembly.

The IPNS-I target shown in Fig. II-F.1 is made up of 4-inch diam, 1-inch thick uranium discs clad on all surfaces with 0.020 inch of Zircaloy 2. Eight of these discs are stacked together with cooling channel spacers between the discs to form the target assembly. The assembly is housed within an outer vessel of stainless steel which serves as a coolant pressure and containment vessel. The target heat load of 20 kW is removed by circulating demineralized light water across the flat surfaces of the target discs. The heat is released via a primary-to-secondary heat exchanger.

The IPNS-I target design has been analyzed for thermal and stress responses using a combination of high-energy neutron transport calculations (HETC) to determine spacial energy deposition, thermal transport calculations (THTB) to determine temperature distributions and elastic stress analysis (MARC/CDC) to determine the resultant stresses. The IPNS-I design basis proton beam is 5×10^{12} protons/pulse at 30 Hz and 500 MeV. The particle distribution is assumed to be parabolic with a FWHM of 4.0 cm. The results of this analysis indicate that the maximum operating centerline temperature is 275 °C. This peak temperature occurs on the target axis 6 cm from the front target face. The elastic stresses were evaluated for the worst case target disc where the temperature is 275 °C at the center and drops radially and axially to a wall temperature of 80 °C. The resultant stresses from such an analysis show that yield stress of the uranium may be exceeded by 20% at the point of maximum stress. The stresses in the Zircaloy cladding reach only about 60% of the yield stress. Limiting the maximum uranium temperature to 275 °C will insure that "ratchetting" growth will not occur. Calculations of uranium growth due to nuclear interactions, i.e., gas formation, cavitation swelling, etc., indicate that such growth will not be lifetime limiting. The most probable mechanism for ultimate target failure appears to be cracking of the Zircaloy cladding due to fatigue resulting from thermal cycling of the target. Such cycling results from the startup and shutdown of the proton beam and not from the pulsed nature of the beam. It is estimated that the target lifetime will be at least 10^4 cycles.

A solid uranium target 3.25 inches diam by 6 inches long has been successfully clad with 0.060 inch of Zircaloy using the process of High Temperature Isostatic Pressing (HIP). The target shown in Fig. II-F.2 was fabricated at Argonne and shipped to Battelle, Columbus Laboratories for HIP bonding. The bonding process involved heating the assembly to 840 °C and applying 15,000 psi externally. These conditions were held for three hours followed by a slow cool (~ 2 °C/minute) to 500 °C and 12,000 psi. These conditions were held for one hour for stress relieving. The unit was then cooled slowly to ambient. Ultrasonic inspection of the bonding interface indicates the presence of a perfect diffusion bond over all of the clad surfaces.

An important consideration in maintaining the integrity of the target is maintaining the proton beam within acceptable limits. This is particularly true of beam diameter. Calculations show that a beam of less than 3.5 cm FWHM for an extended duration could cause premature cladding failure.

The design of the target cooling system is based on a coolant velocity of 15 ft/s with an inlet temperature of 49 °C. A static pressure of 20 psig at the target outlet insures a factor of ~ 3 between the burnout heat flux and the calculated maximum heat flow.

The target assembly is housed within a two-region cylindrical reflector of beryllium. The overall reflector assembly is shown schematically in Fig. II-F.3. Figure II-F.4 is a vertical section of the inner reflector region. Four moderators are arranged within this region in a "wing" geometry with the target. Two rectangular moderators below the target provide the source neutrons for nine neutron-beam tubes. A third rectangular moderator above the target is viewed by three more beam tubes. A cylindrical moderator above the target provides a dedicated source of ultracold neutrons which travel vertically upward through a beryllium filter to the top surface of the biological shield. All of the moderators will be designed to be cooled to 20 °K and could contain either liquid or solid moderator materials. The inner reflector assembly is designed to be removable for modification or replacement with a different geometry.

The neutron-scattering reflector assembly is housed in a cavity within the biological shield. Figure II-F.5 shows the layout of the biological shield. The 12 horizontal neutron-scattering beam tubes are arranged symetrically around the reflector with an angular separation of 18°. Provisions are made within the shield for an experimental proton beam and two horizontal, multipurpose neutron beams at ± 15° from the forward direction. The basic shield composition is ~ 12 feet of iron in the forward direction and ~ 8 feet of iron at 90°. An outer layer of concrete and absorber material serves as a thermal neutron absorber and gamma shield. The biological shield is designed for a dose rate of 0.5 mrem/h. Figure II-F.6 is a vertical section through the biological shield showing a typical neutron-beam tube. The minimum beam-tube size is 10 inches by 18 inches to accommodate beam plugs with apertures viewing the moderators in either the wing or slab geometry. The figure also shows a concept for the equipment cavity and beam gate.

At the interface of the concrete and steel of the biological shield is a metal liner which forms a gas-tight volume within which the atmosphere can be controlled. It is important to eliminate air from the cracks and joints of the stacked steel shielding. Thermal neutron irradiation of such air results in the production of ^{41}Ar and the formation of nitric acid (if the air contains moisture). A low pressure helium atmosphere will be maintained within this enclosed volume to prevent these problems.

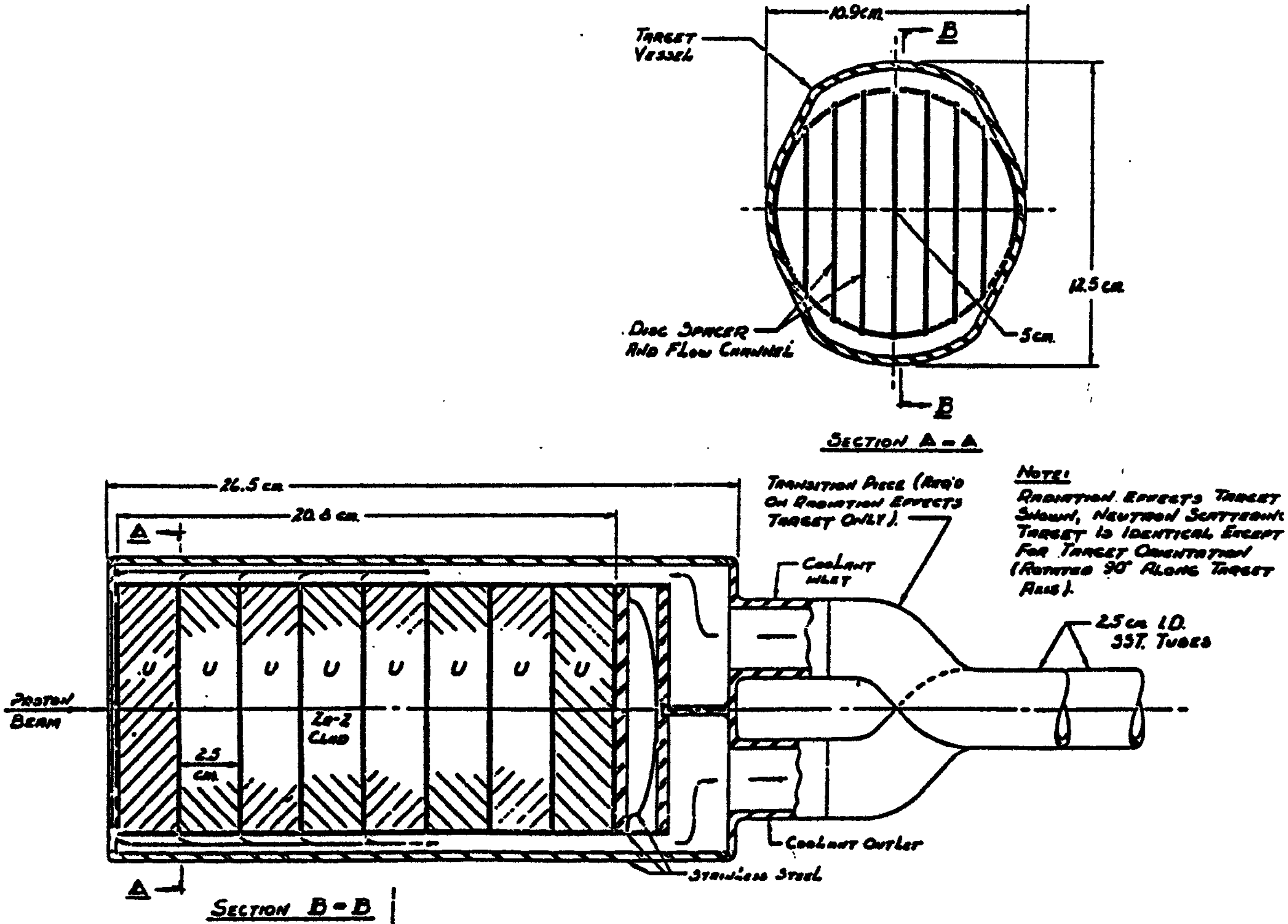

Fig. II-F.1. IPNS-I target assembly conceptual design.

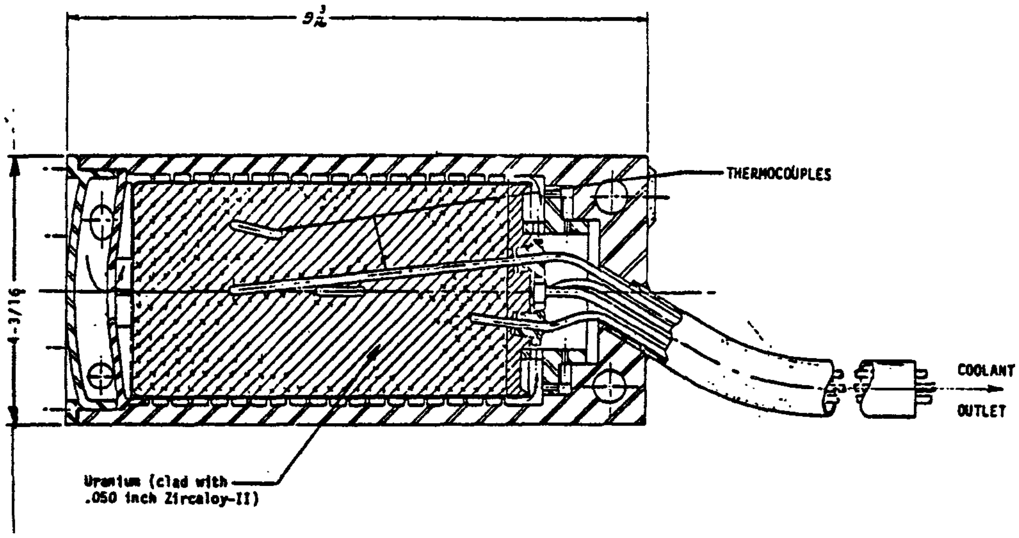

Fig. II-F.2. ZING-P' uranium target assembly.

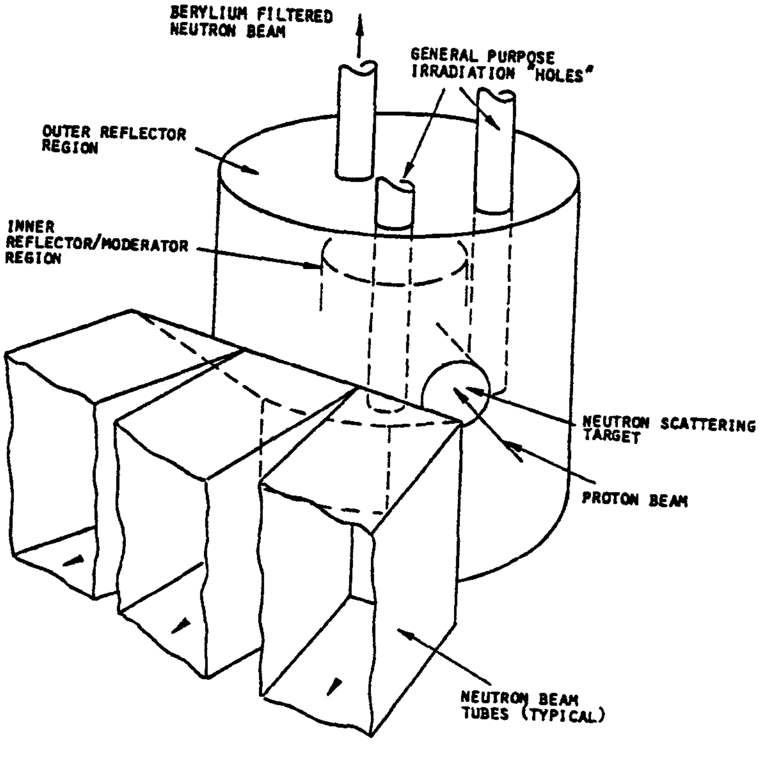

Fig. II-F.3. IPNS-I neutron scattering experimental assembly.

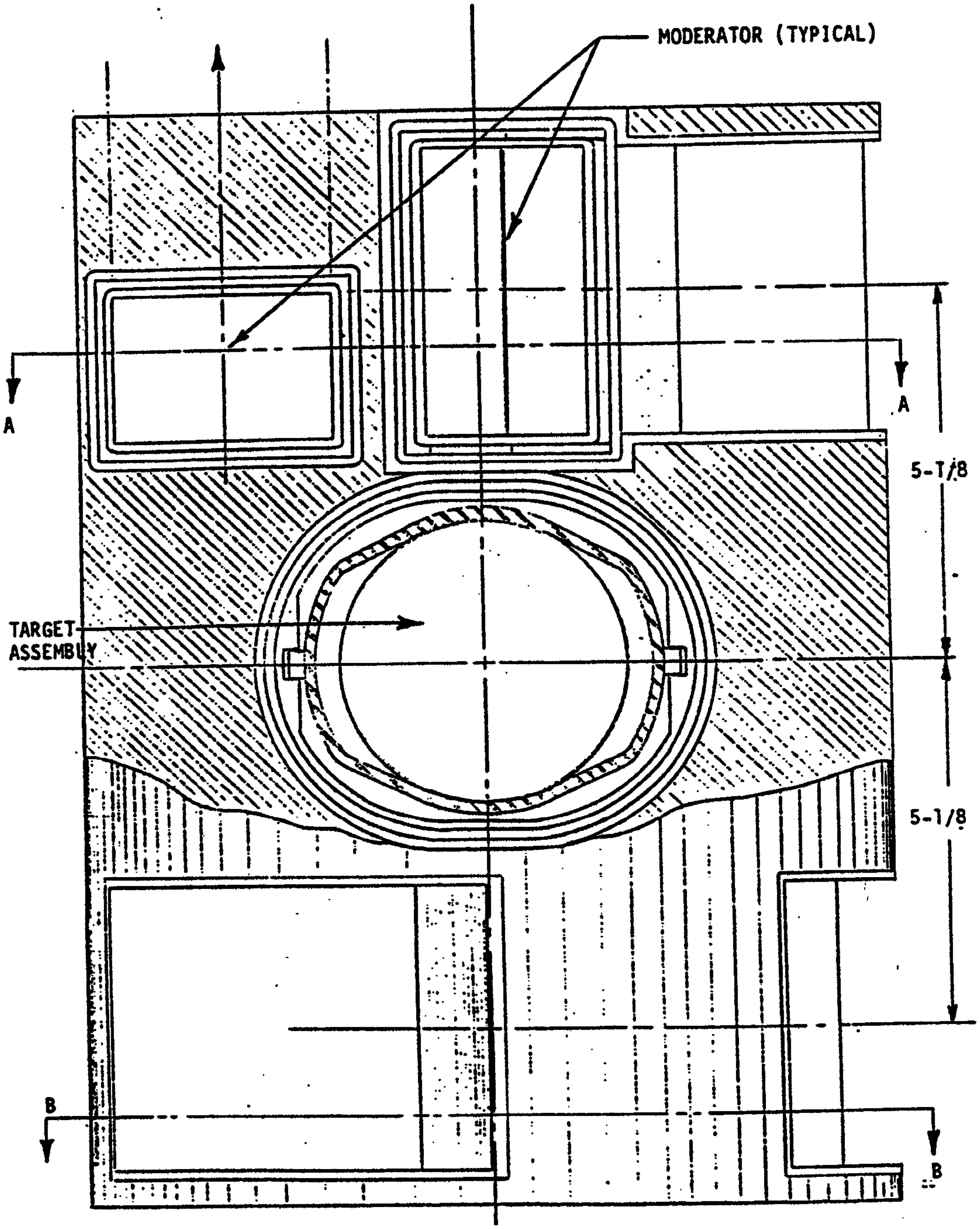

Fig. II-F.4. Inner reflector region of IPNS-I neutron scattering experimental assembly.

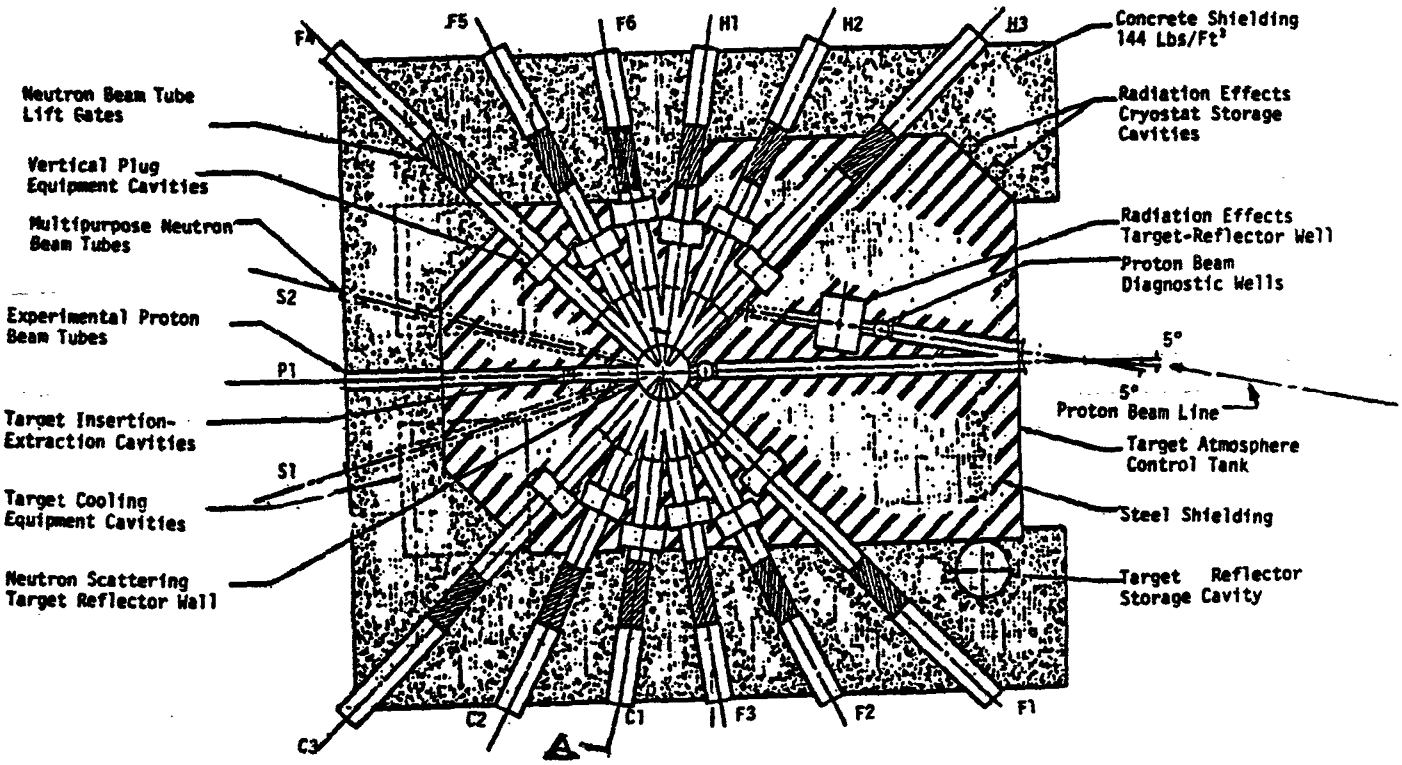

Fig. II-F.5. IPNS-I biological shield layout.

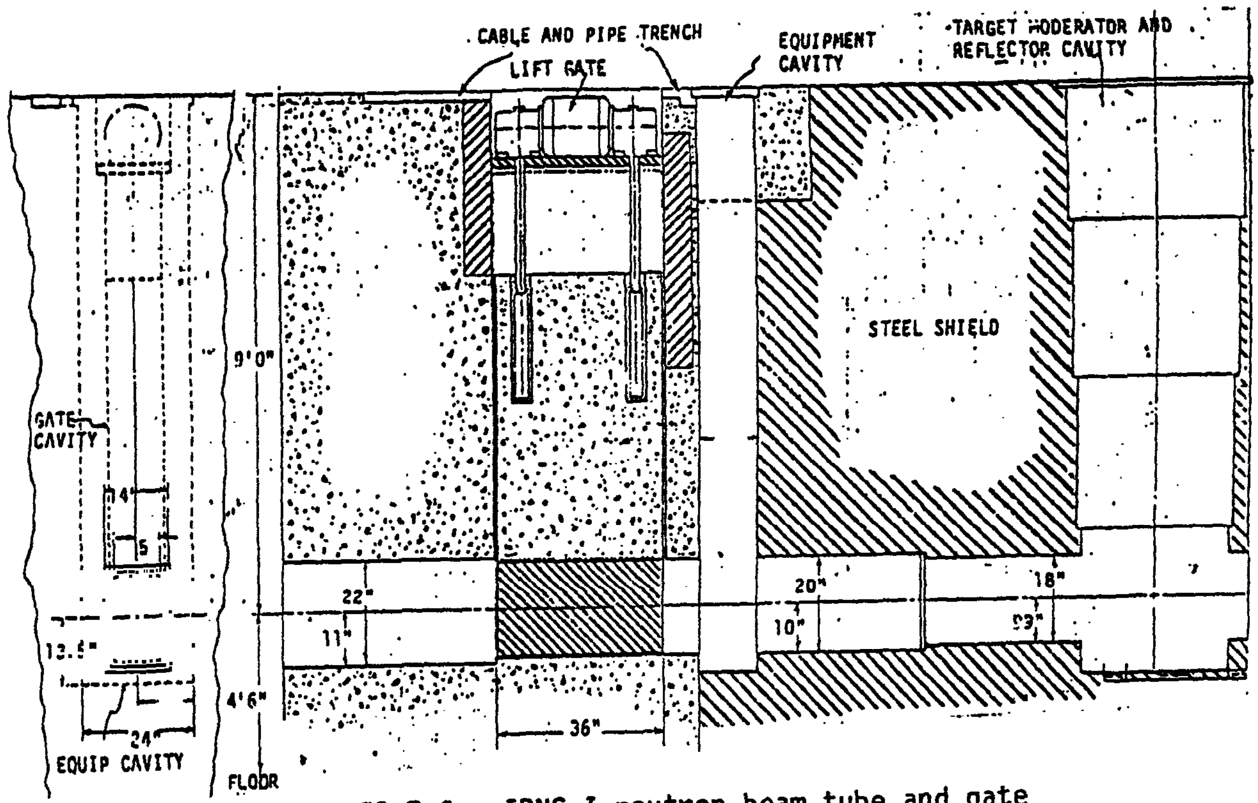

Fig. II-F.6. IPNS-I neutron-beam tube and gate arrangement - conceptual.