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THE ADVANCED NEUTRON SOURCE

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Introduction

Neutron scattering was pioneered by C. G. Shull and E. O. Wollan at the X-10 (natural uranium) graphite reactor at Oak Ridge National Laboratory about half a century ago. The flux available, although low ($1 \cdot 10^{16}$ $m^{-2} \cdot s^{-1}$), was sufficient to show the importance of neutron scattering as a fundamental technique in materials science. Many reactors of increasingly higher flux were designed and built in the 1950's and 1960's, culminating with the high flux reactors at Brookhaven National Laboratory (HFBR) and at Oak Ridge National Laboratory (HFIR) in the United States, and at the Institut Laue-Langevin in France; all of these reactors offer fluxes of order $1.5 \cdot 10^{19}$ $m^{-2} \cdot s^{-1}$. However, while new research reactors have either come on-line (or are about to come on-line) since that time in Western Europe, Japan, and Russia, it is now about 25 years since the last research reactor was constructed in the United States. By the late 1970's, it was clear that the lead in the field of neutron scattering had passed decisively to Western Europe. In 1983, the National Research Council reviewed the needs of neutron scattering *per se* [1] and the neutron scattering facilities existing in the United States [2].

The major facilities review concluded that a new, steady-state high-flux neutron facility was a high priority requirement for the United States, and recommended that design begin immediately. Among the factors contributing to this recommendation was the age of existing reactors, the evident European leadership in a field in which the U.S. had been predominant, and the important (and often unique) future applications of neutron scattering in many important areas of condensed matter physics, polymer and colloid science, metals, alloys and ceramics, chemistry, biology and medicine, and the earth sciences. The detailed needs of the community, as defined in several major workshops [3-5], helped to define the Advanced Neutron Source project. The fundamental project objective is to design and construct the world's highest flux research reactor for neutron scattering, together with state-of-the-art instrumentation. The reactor will also provide isotope production and materials irradiation facilities which are as good as, or better than, any presently operational source.

The Neutron Source

The *sine qua non* of the new facility is a reactor which can provide a flux at least five times higher than any existing neutron beam reactor, while meeting extremely stringent safety requirements. To this end, it was decided to base the design as much as possible on existing technology (although advantage will be taken of any gains from new research and development), and to carry out probabilistic risk assessment simultaneously with design; the latter is a first for such a project, and reflects the fact that safety considerations are of primordial concern. A major achievement of the project has been the completion of the preconceptual nuclear and

thermal hydraulic design of the reactor, showing that the objectives can be met with a safe design. The key feature has been to choose a coaxial, split-core in which the two halves are axially displaced and separately cooled (see Figs. 1 and 2). The reactor volume of 67.4 L contains 18 kg of ^{235}U (93% enriched) in the form of involute plates of U_3Si_2 in an Al matrix. The unperturbed peak thermal flux generated in the reflector is of order $9 \cdot 10^{19}$ $m^{-2} \cdot s^{-1}$ at a power of 350 MW. The reactor core is cooled by a heavy water primary coolant loop, with coolant *upflow*. The choice of upflow provides a very desirable added safety feature, since it ensures an immediate transition to natural convection cooling (without any time delay for flow reversal) in the unlikely event of rupture of the primary circuit at a point which forestalls compensation by the independent backup circuit. (It should be noted that the normally low probability of major pipe rupture is being further reduced by designing for leak-before-break, with continuous leak monitoring.) The maximum coolant outlet temperature is 98°C, so that boiling will not occur on loss of pressure.

The reactor is controlled by four hafnium control rods in the central core channel. Each rod is provided with an independent scram mechanism, and any three of the four are able to shut down the reactor. A second, independent, shutdown mechanism is provided by eight shutdown rods placed outside the core. Each rod is again provided with an independent scram mechanism, and any seven of the rods are sufficient for total shutdown. Thus, the reactor may be shut down, even if there is total failure of one complete set of independent scram mechanisms, and partial failure of the other.

There are six major types of experimental facilities in the reactor assembly (Fig. 2). Materials irradiation (for example, for fusion research) takes place in capsules placed inside the upper fuel element, while transuranium elements are produced in targets just outside the lower fuel element. One of the achievements of the core design is that these facilities, which provide appropriate fast and epithermal neutron spectra, have minimal effect (<2%) on the fluxes of the neutron beams to the

experiments. The large volume of high thermal flux available in the reflector tank is well suited to isotope production and analytical chemistry operations. To accomodate these activities, various experiment holes and "rabbit" tubes penetrate the top of the reflector tank. Seven vertical and two slant holes will provide a range of thermal fluxes for isotope production; these holes will be complemented by four hydraulic rabbit tubes, and at least three pneumatic rabbit tubes for materials analysis.

Neutron beams are extracted from the reflector by beam tubes which penetrate either into the peak thermal flux region (about 400 mm from the core centerline), or terminate at the graphite hot source at the reflector tank wall. The hot source is one of two types of spectral convertor which are placed in the reflector to tailor beam energies for specific applications; conversion to sub-thermal energies is accomplished by two liquid-D_2 cold sources. Cold neutrons are transported by horizontal neutron guides into a neutron guide hall adjacent to the containment building, or by slant guides to the second-floor beam room.

Neutron Scattering Facilities

There will be three user halls provided for experimental work at the ANS (Fig. 3). The *Ground Floor Beam Room* will provide "conventional" access to thermal and hot neutrons from the reactor *via* horizontal beam tubes terminating at the outside of the biological shielding. Inclined beams and certain other services, such as rabbit tubes, will terminate on a higher level in the *Second Floor Experiment Room*. Very cold and ultracold neutron research will take place on this level, as well as such activities as neutron depth profiling and some of the fundamental and nuclear physics work. The third main experimental area is the *Neutron Guide Hall*, which will

provide the primary instrumentation for cool and cold neutron research. The layouts presented below are tentative, as they are designed to accommodate *today's* needs and priorities [3,4].

Ground Floor Beam Room. - The ground floor beam room layout is shown in Fig. 4. This layout currently assumes that, apart from a single through tube for nuclear physics, all beams will lie in the same plane; as neutronics calculations evolve, it may become necessary to stagger the beam heights alternatively above and below this reference plane, to minimize flux perturbations due to the beam tubes themselves.

Thermal beam scattering instruments for diffraction include 4-circle diffractometers on a thermal tube (T1) or guide (T2). A polarized beam is earmarked for single crystal diffraction (T3), but, in general, it is expected that polarized neutrons (and polarization analysis) will be routinely available whenever warranted on any instrument on the ANS. High resolution (T4) and high intensity (T5) powder diffractometers and two diffuse scattering spectrometers (T6/7) complement the single crystal instruments. Inelastic spectrometers are time-of-flight (T8) or 3-axis (T11/12).

The hot source provides beams to a high energy transfer 3-axis spectrometer (H3), a high momentum transfer single crystal diffractometer (H1), and a general purpose high incident energy diffractometer (H2) for studies of liquids and amorphous materials.

Neutron Guide Hall. - The guide hall building (Fig. 5) is a wedge-shaped, single floor structure contiguous with the reactor containment building and office/laboratory complex. Two polar segment cranes will serve the guides and instruments. The guide shield structure reaches out to a distance of about 50 m from the reactor axis, and the experiment area extends a further 60 m. Apart from the two extreme guides, which serve special positions for nuclear physics (L12) or

materials analysis (D16), the guides will generally be straight, so that cool as well as cold energies will be available. It will be noted that about one third of the experimental stations are for nuclear or fundamental physics; only the scattering instruments will be described here.

The most prevalent elastic scattering instruments are the small-angle neutron scattering cameras ((D3-6, L1, L2, L11), which offer varying degrees of resolution, and at least one of which will have reflectometer capabilities for surface studies. Diffuse scattering and high resolution powder diffraction will be available (L5, L6), together with a general purpose area detector for efficiently scanning large regions of reciprocal space, for example, to study incommensurable lattice structures. A specially isolated mounting (to screen thermal and acoustic noise) will be provided for a neutron interferometer station (L7).

Conventional, variable k_o, focussing monochromator cool and cold 3-axis spectrometers will be the workhorses for inelastic scattering studies in the guide hall (D11, D12, L8, L9, L10), together with multichopper (D1) and time focussing (D9) time-of-flight spectrometers. Higher resolution inelastic studies will use backscattering (L4, D10) or neutron spin-echo (D2) as appropriate.

Second Floor Experiment Room. - The main purpose of the second floor of the containment building is to provide experimental areas for users of the inclined beams and guides (Figs. 3 and 6). The prototypical layout shown in Fig. 6 demonstrates several key features, of which the most notable is the division of the area into two zones, one *secure*, the other *general access*. This is a particular example of the general site philosophy adopted for the ANS plant: separation of reactor operations from experimental areas, so that users may have straightforward access to their experiments and related areas (such as chemical laboratories), without requiring access to high security zones. One important role played by the

second floor beam room will thus be to accommodate those experiments which have more commonly been situated in the reactor operations areas of other reactors (such as the ultracold neutron facility at ILL, Grenoble).

Current plans call for each cold source to be fitted with an inclined, curved guide (Fig. 3) for very cold neutrons (VCN). It is likely that one of these will be used directly while the other will be used as a feed for an ultracold (UCN) source (Fig. 6). A cold slant guide will provide a station for neutron depth profiling (NDP), which is a sensitive means of measuring concentration *vs* depth profiles by using reactions such as $^{10}B(n,\alpha)^{7}Li$ and detecting the resulting charged particles, whose range is a strong function of the distance they must travel in the surface being probed. NDP, which is quantitative and non-destructive, is applicable to a variety of technologies, such as microelectronics, optical signal processing, ultra-light alloys, and surface-modified materials.

A novel possibility for the ANS is to provide isotope separation on-line (ISOL). In this technique, a fission-fragment mass separator is used as the front end of an ion-implantation accelerator, providing a number of unique ions for studies of electron emission, channelling, and hyperfine interactions associated with ion-implanted radioactive atoms. Since charged beams are involved, they may be transported to ancillary equipment situated at some distance from the reactor.

Project Schedule and Cost.

The conceptual design phase of the ANS project will be finished at the end of 1990. Conceptual design embraces, apart from the key engineering elements, the choice of a site which meets all environmental criteria, and the considerable plant and equipment associated with the research activities planned at the ANS, for

example offices, workshops and laboratories, library and conference rooms, *etc.* The next stage is preliminary engineering design, and if approved this would lead to a complete design by 1993, with construction currently planned to start in 1994. The total project cost is currently estimated to be between $650M and $800M (1990 dollars), spread over 9 years. If the schedule is maintained, this will lead to reactor operation in late 1998, and will take the U.S. materials science community into the next millenium with the world's best facility of this type.

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[4] G. H. LANDER and V. J. EMERY, Editors: *Proceedings of the Workshop on Scientific Opportunities with Advanced Facilities for Neutron Scattering*, Argonne National Laboratory Report CONF-8410256 (1984); Nucl. Instr. and Meth., **B12**, 525 (1985)

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CAPTIONS FOR FIGURES

Fig. 1. - The ANS two-element reactor. Each element is cooled by a separate coolant upflow. The coaxial elements are separated along the vertical axis, as shown in Fig. 2.

Fig. 2. - The ANS reactor assembly, showing the fuel elements with their associated control systems in the heavy water reflector tank. The configuration of major experimental facilities associated with the reflector tank is also shown.

Fig. 3. - A vertical section through the ANS reactor containment building.

Fig. 4. - The ground floor beam room.

Fig. 5. - The cold neutron guide hall.

Fig. 6. - A tentative arrangement of the second floor beam room.

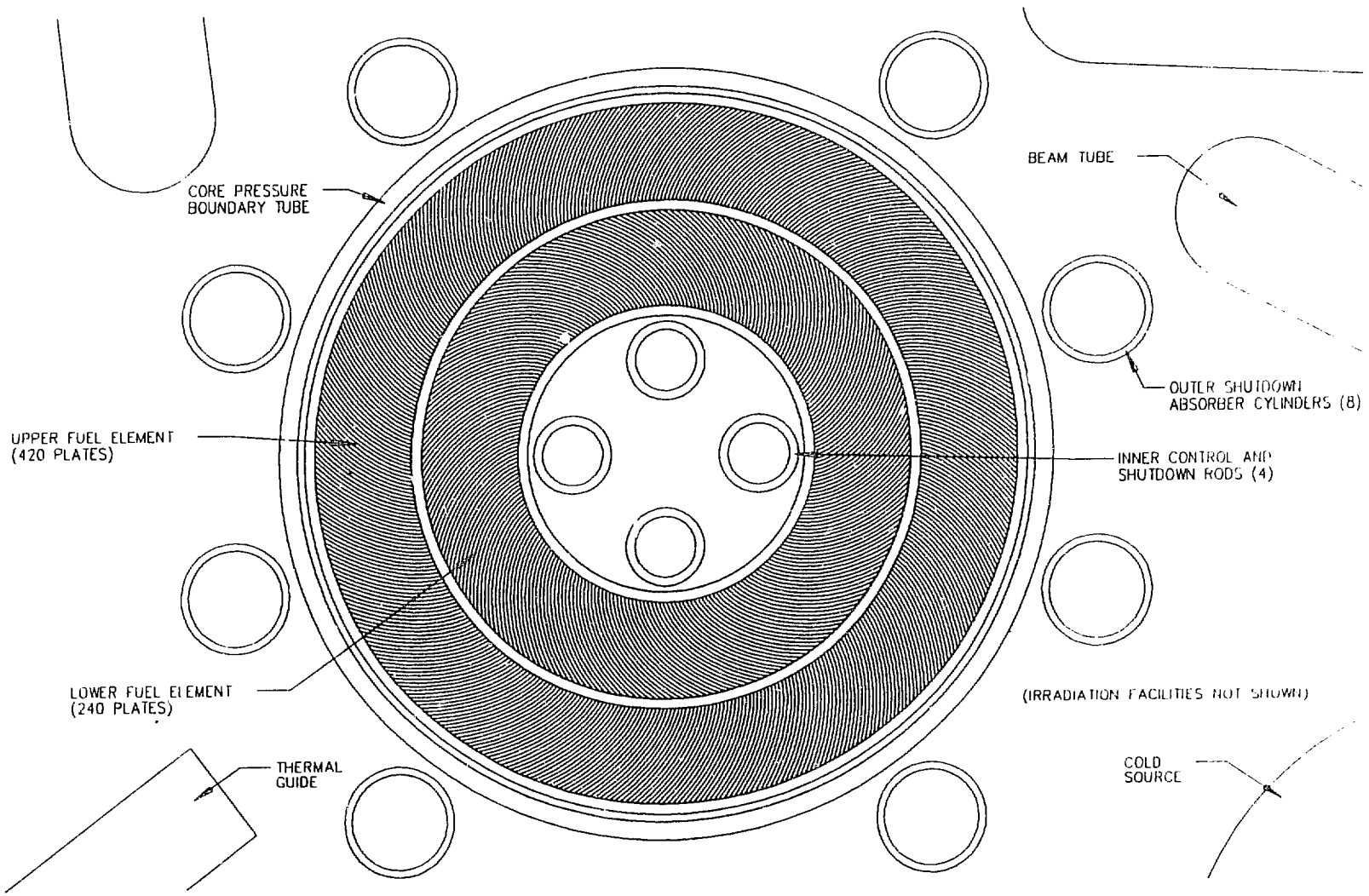
CORE PRESSURE
BOUNDARY TUBE
BEAM TUBE
OUTER SHUTDOWN
ABSORBER CYLINDERS (8)
UPPER FUEL ELEMENT
(420 PLATES)
INNER CONTROL AND
SHUTDOWN RODS (4)
LOWER FUEL ELEMENT
(240 PLATES)
(IRRADIATION FACILITIES NOT SHOWN)
THERMAL
GUIDE
COLD
SOURCE

FIG. 1

(HAYTER)

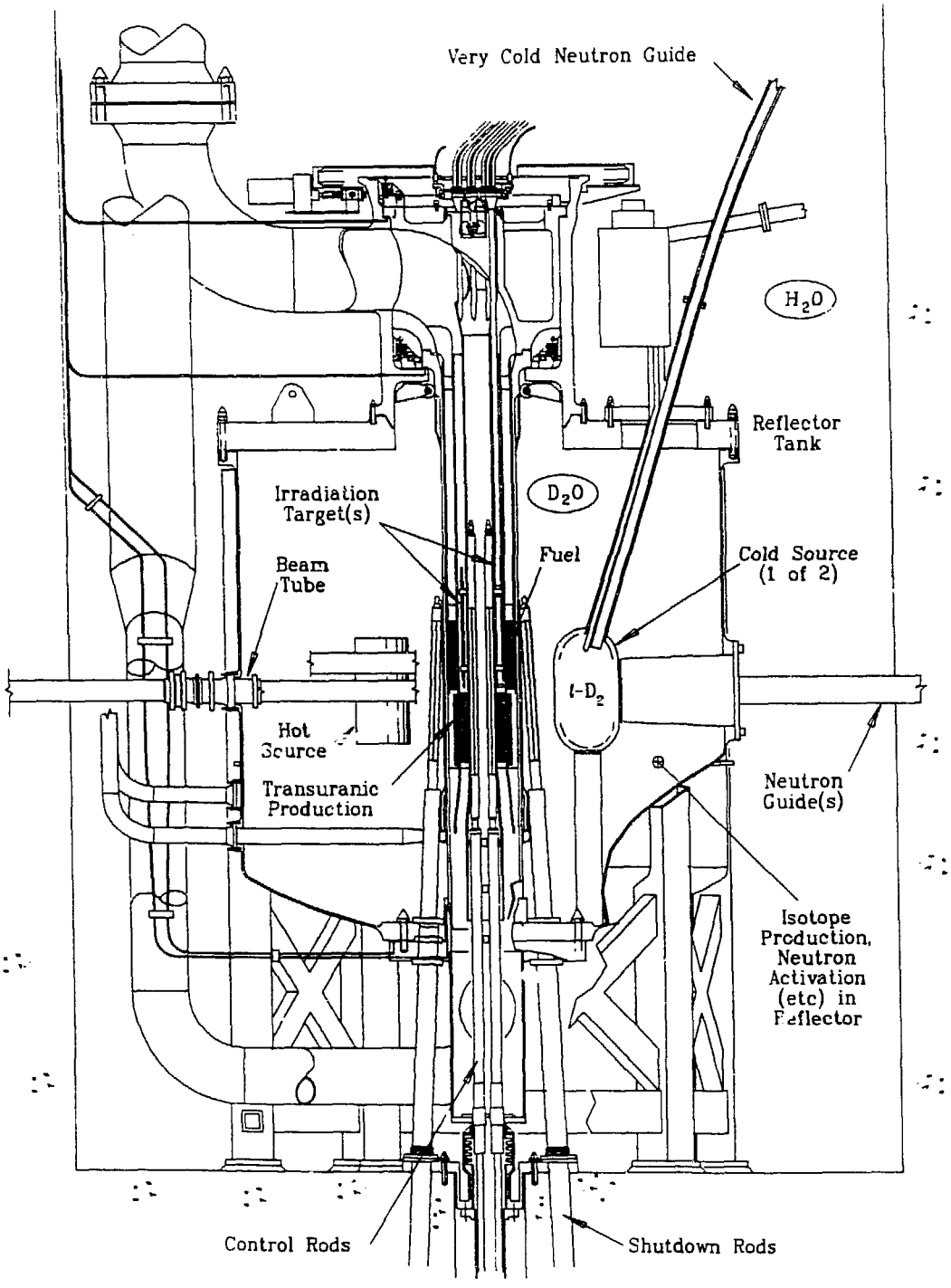
Very Cold Neutron Guide
H_2O
Reflector Tank
D_2O
Irradiation Target(s)
Beam Tube
Fuel
Cold Source (1 of 2)
$t\text{-}D_2$
Hot Source
Transuranic Production
Neutron Guide(s)
Isotope Production, Neutron Activation (etc) in Reflector
Control Rods
Shutdown Rods

FIG. 2

(HAYTER)

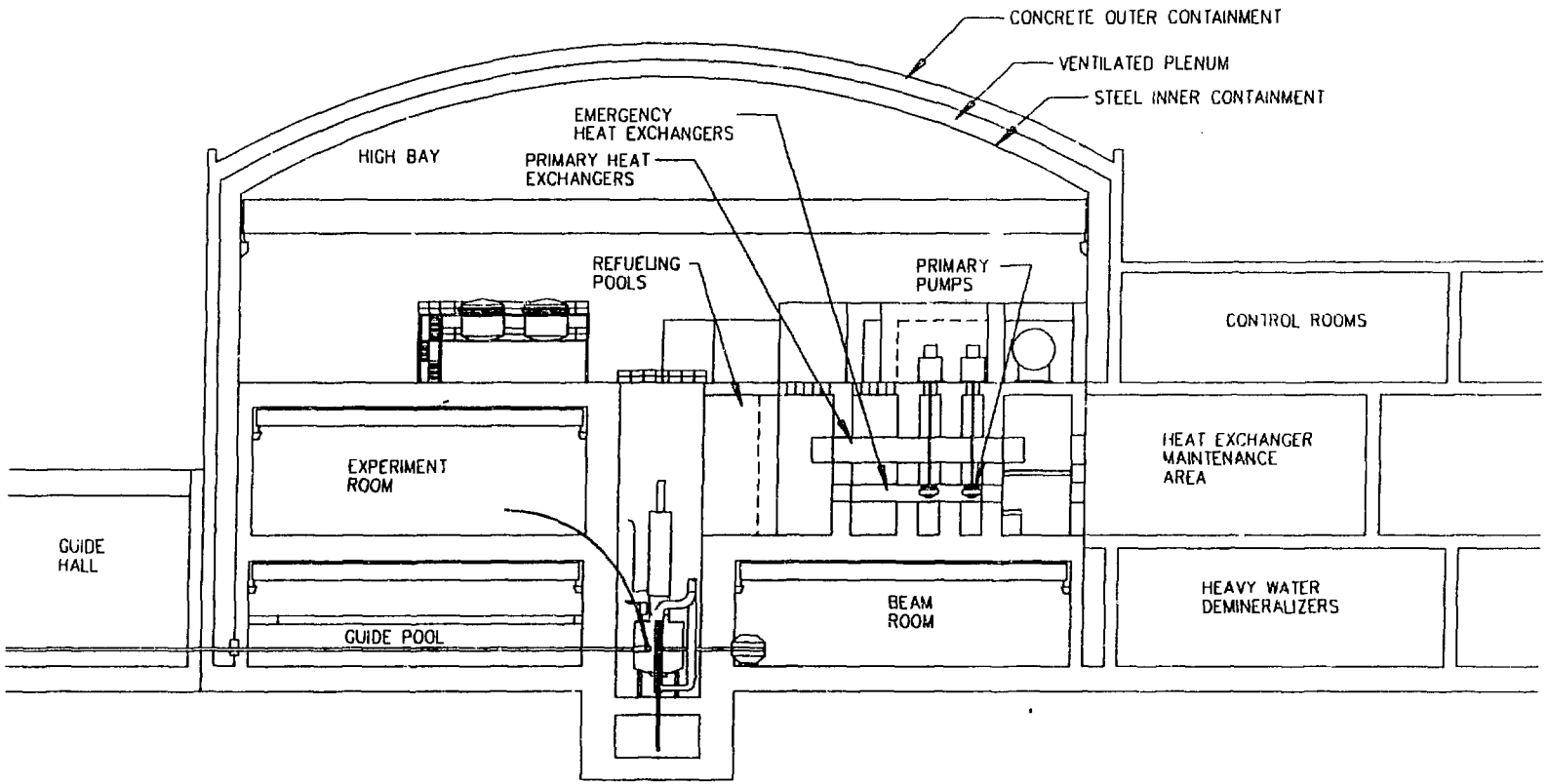

FIG. 3

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(3 of 6)

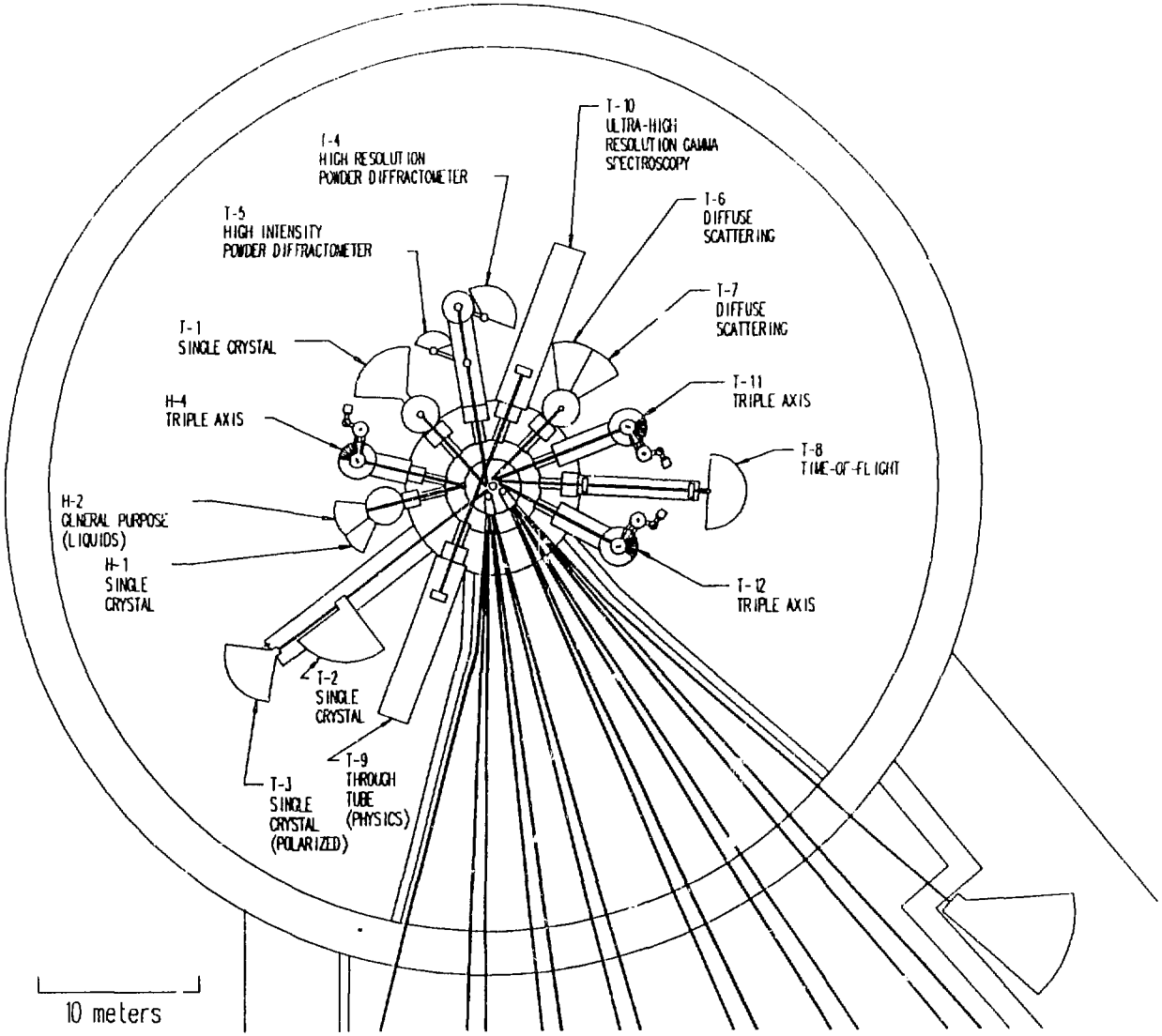

FIG. 4

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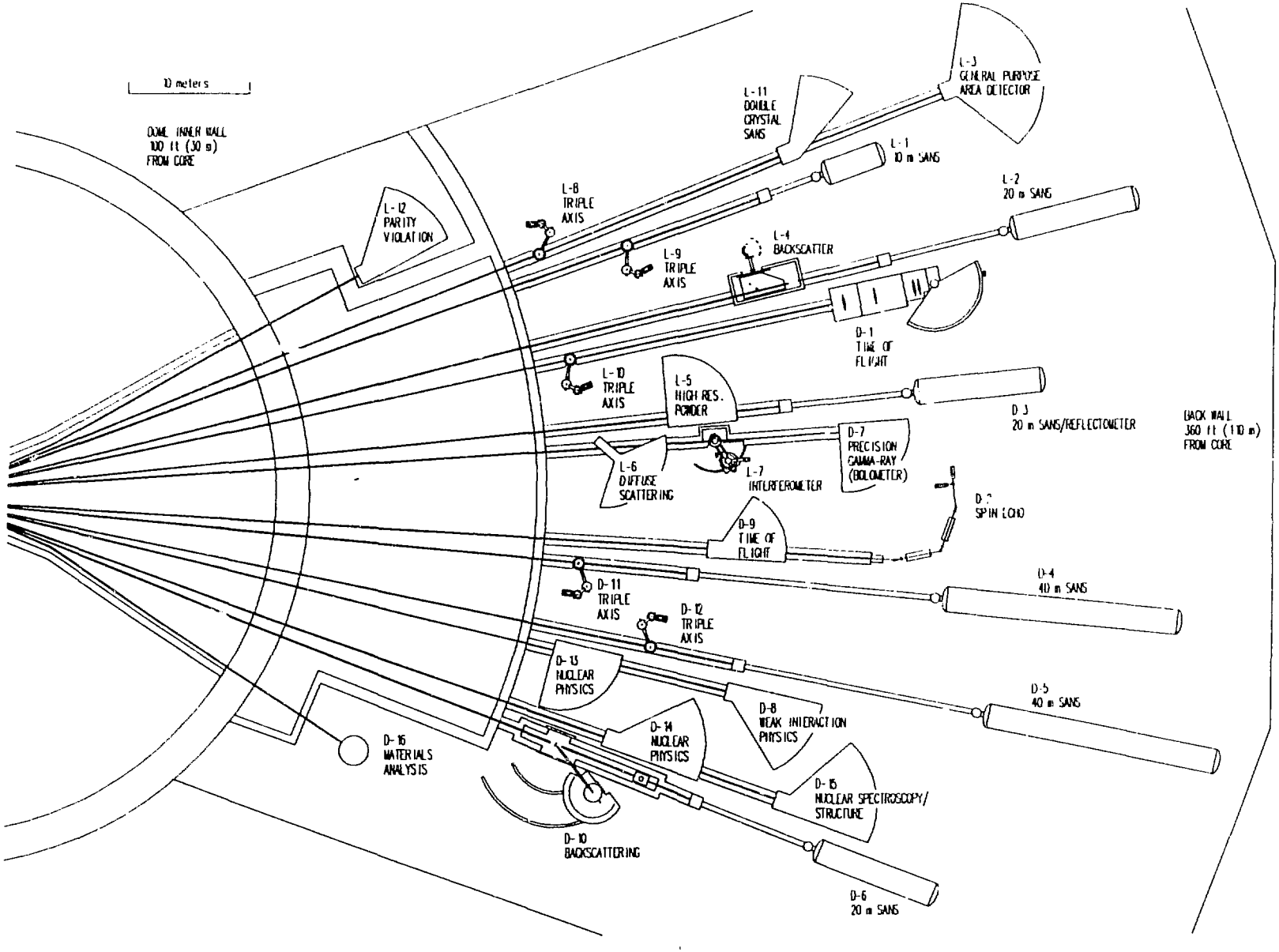
10 meters
DOME INNER WALL
100 ft (30 m)
FROM CORE
L-12
PARITY
VIOLATION
L-8
TRIPLE
AXIS
L-9
TRIPLE
AXIS
L-11
DOUBLE
CRYSTAL
SANS
L-3
GENERAL PURPOSE
AREA DETECTOR
L-1
10 m SANS
L-2
20 m SANS
L-4
BACKSCATTER
D-1
TIME OF
FLIGHT
L-10
TRIPLE
AXIS
L-5
HIGH RES.
POWDER
D-3
20 m SANS/REFLECTOMETER
BACK WALL
360 ft (110 m)
FROM CORE
D-7
PRECISION
GAMMA-RAY
(BOLOMETER)
L-6
DIFFUSE
SCATTERING
L-7
INTERFEROMETER
D-?
SPIN ECHO
D-9
TIME OF
FLIGHT
D-4
40 m SANS
D-11
TRIPLE
AXIS
D-12
TRIPLE
AXIS
D-13
NUCLEAR
PHYSICS
D-5
40 m SANS
D-8
WEAK INTERACTION
PHYSICS
D-14
NUCLEAR
PHYSICS
D-16
MATERIALS
ANALYSIS
D-15
NUCLEAR SPECTROSCOPY/
STRUCTURE
D-10
BACKSCATTERING
D-6
20 m SANS

FIG. 5

(HAYTER)

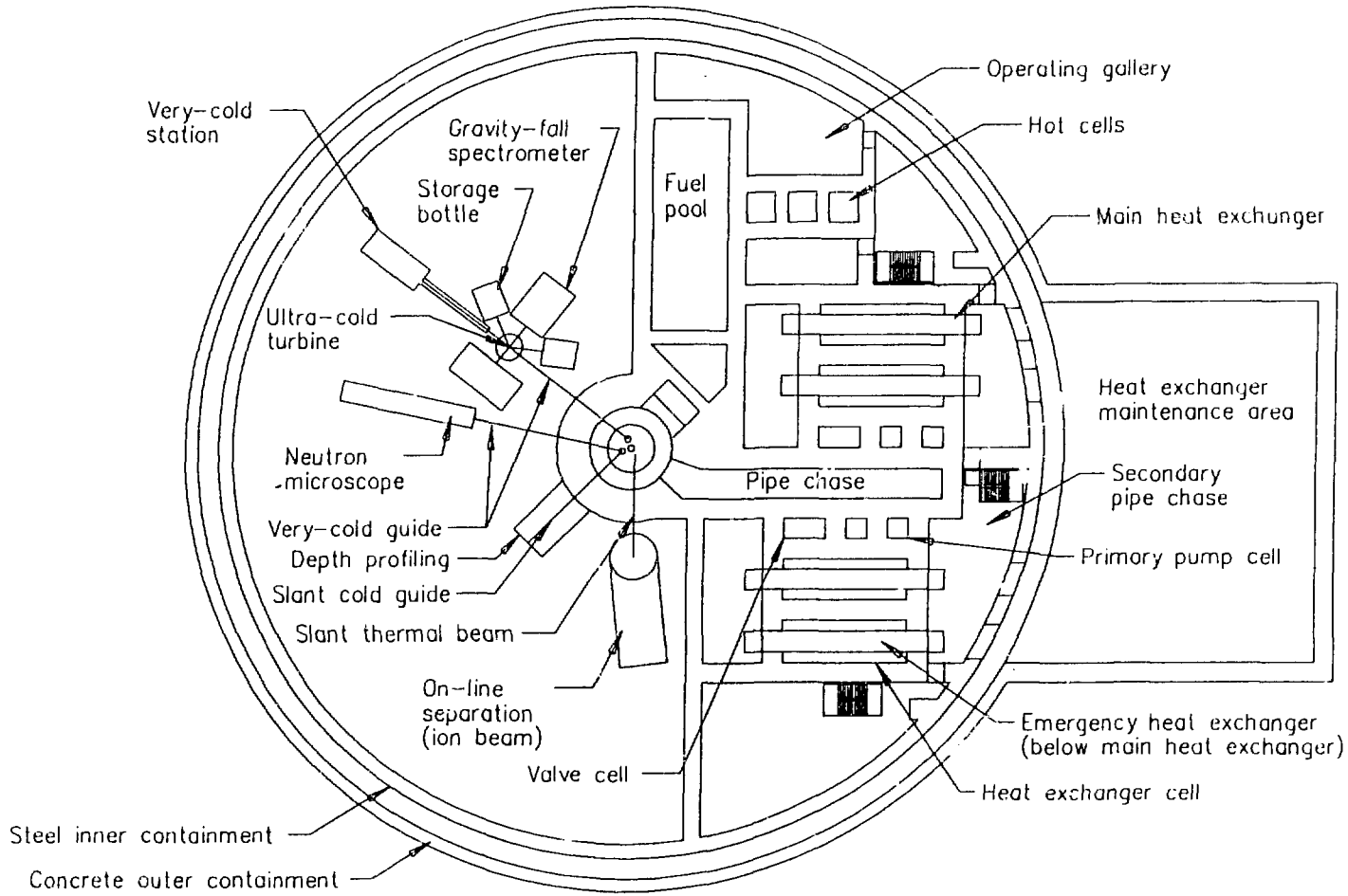

FIG. 6

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6 of 6