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EXPERIMENTAL FACILITIES

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The opportunity to provide new, improved experimental facilities in a new reactor is at least as important as the higher neutron flux expected from the reactor. The present generation of U.S. research reactors was constructed before the development, largely in Western Europe, of many innovations in the technology of delivering neutrons to the sample and of instrument design. Major reconstruction of an existing reactor or construction of an entirely new facility is necessary to take full advantage of these innovations.

In the present preconceptual design phase of the HFIR-II project both of these options will be considered. We have completed an engineering feasibility study of a major modification of the HFIR facility and are now beginning a similar study of an entirely new facility. The design of the reactor itself is common to both options. In this paper a general description of the modified HFIR is presented with some indications of the additional facilities that might be available in an entirely new facility.

We will discuss the proposed neutron beam facilities for scattering experiments and for nuclear physics but we are committed also to provide improved facilities for isotope production, for materials irradiation, and for neutron activation analysis. Additional facilities to be considered include γ-ray diffraction, positron production, depth profiling, and neutron radiography.

The two major current problems with the HFIR facility are the limited number of horizontal beams (4) and the limited floor space for experimental apparatus. The proposed concept solves these problems by creating a large experimental guide hall (210' x 200') with eight beam guides, enlarging the existing experimental space in the beam room, and adding three more horizontal beams. The guides exit the reactor on the side not presently used for beam tubes, pass under the storage pool in a transition region which can be used for bending the guides, and then enter the new guide hall. The concept is illustrated in Fig. 1. Two cold sources in the D_2O reflector supply cold neutrons to six guides, and there are two thermal guides. A hot source feeds two horizontal beams in the enlarged beam room. Four slant tubes (2 thermal, 1 hot, 1 cold) deliver neutrons to an experimental area on the floor above the beam level floor. The array of beams is summarized in Table 1. It is anticipated that the thermal and hot tubes will see source fluxes of 4-5 x 10^{15} n/cm^2 sec. Also shown in Table 1 is a tentative distribution of beams for an entirely new facility.

Certainly one of the most important advantages of the proposed facility is the enormous increase in cold neutron capability. The two cold sources and multiple beam guides would provide unmatched cold neutron facilities.

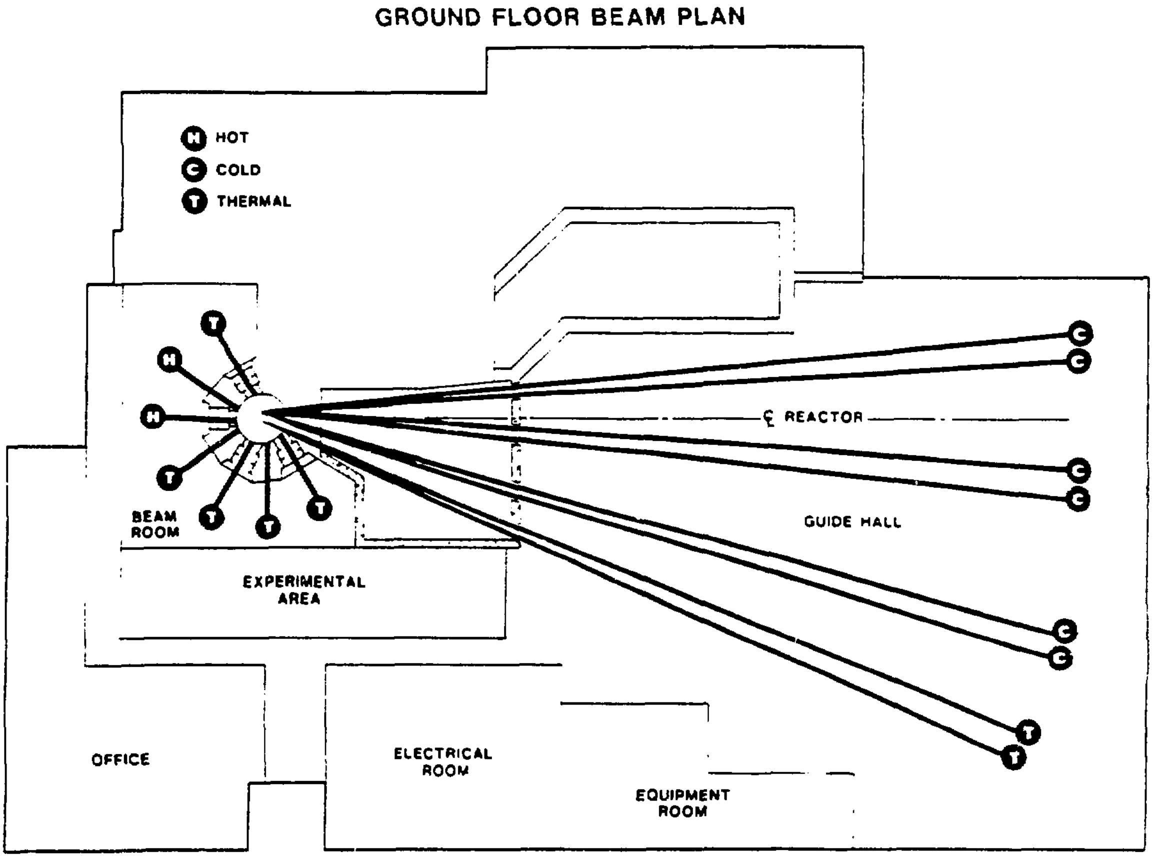

Fig. 1. Conceptual plan for horizontal beams at a modified HFIR facility.

Table 1. Proposed Beam Lines

Type	Energy	Dimensions (cm)	Modified HFIR No.	New Facility No.
Horizontal Tube	Thermal	10 x 15	5	8
	Hot	10 x 15	2	2
Slant Tube	Thermal	10 diam.	2	3
	Hot	10 diam.	1	1
	Cold	10 diam.	1	2
Horizontal guide	Cold	4 x 15	6	8
	Thermal	4 x 15	2	0

For example, a small-angle scattering instrument could be constructed with resolution similar to that of the 30-meter instrument now at the HFIR but with a gain in neutron intensity of about 100 (5 from reactor flux, 10 from the cold source, and 2 from changing from a double-crystal monochromator to a velocity selector).

We are planning to install a hot source even though an argument can be made that hot neutron research might be accomplished better at a pulsed neutron source. We believe that important results on the structure of liquids and amorphous materials and on dispersive, high-energy excitations could be obtained with an intense, reactor-based hot source.

The slant beam tubes would deliver neutrons to an experimental area on the floor above the horizontal beam room. The present slant tubes have not been used for neutron scattering because they originate in a region of rather low flux at the edge of the Be reflector and have a smaller diameter than the horizontal beams. In the new installation the slant beams should provide a useful flux up by a factor of 25 over the present installation. The design of instruments for these slant tubes is more challenging than for horizontal tubes, but most diffraction (2-axis) instruments could be acomodated on the slant tubes. An ultra-cold neutron installation featuring a guide with a short bending radius is an obvious possibility for one of the slant positions.

For many experiments, significant intensity gains with little loss of resolution can be achieved by relaxing the vertical collimation in the beam tubes. Examples are triple-axis spectrometry, powder diffraction, and diffuse scattering. Two methods for providing greater vertical divergence are to increase the height of the beam tube at the source or to use vertically focusing monochromators. The first method is used at Chalk River where the beam tubes are elliptical with axes of 3 7/8" and 8 7/8". In a vertically focusing monochromator the reflecting planes are curved to form a cylindrical surface so that an image of the source is formed at the sample position. While vertically focusing monochromators are in widespread use, the existing arrangements of beam tube, collimator shutter, and post-monochromator collimation have not been designed to take full advantage of the possible gains. The essential point to remember is that for vertical focusing the intensity at the sample position is proportional to the height of the monochromator; while for a conventional, flat monochromator the central intensity at the sample is proportional to the height of the source.

The basic geometry for the two cases is illustrated in Fig. 2 along with the resulting intensity at the sample position as a function of vertical distance. The total areas under the two intensity curves are equal but the vertical focusing case gives a significant gain in neutrons on the sample for relatively small samples. The beam tubes and associated vertical collimators at the HFIR were designed to produce a central maximum at the sample position about 2" high with a flat monochromator. This means that the beam is about 2.5" high at the monochromator position, which effectively limits the usefulness of vertically focusing monochromators at present. In the new reactor we would provide for the effective utilization of monochromators with significantly greater height.

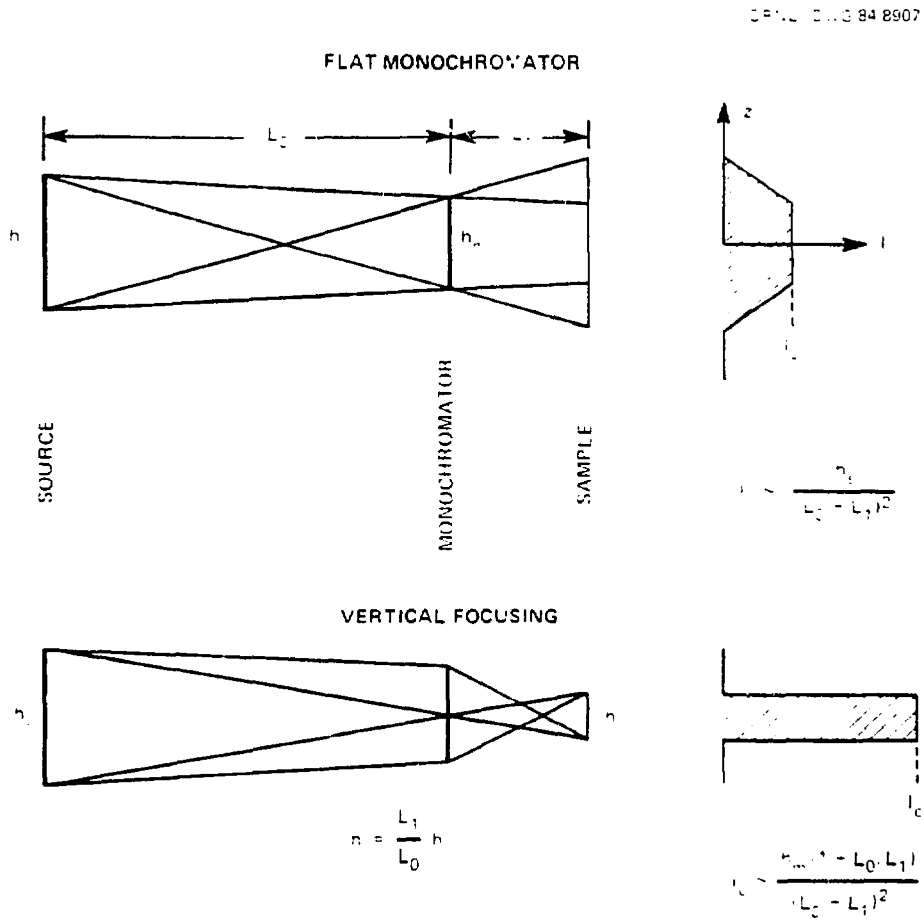

Fig. 2. Intensity comparison for flat and vertical-focusing monochromators.

Possible gains are summarized in Fig. 3 which shows the total number of neutrons incident on a sample as a function of sample height. The source-monochromator-sample separations correspond to an existing HFIR spectrometer. At the present time we are restricted to a source height of 4" and a monochromator height of 2.5". For the new reactor we are considering elliptical or rectangular beam tubes 4" wide and 6" high with vertical collimation which would allow 6" high monochromators. This proposed design would allow gains of 2.4 for small samples and 3.6 for large samples over the best now obtainable at HFIR in addition to the gain achieved by higher source flux. With a flux of 5×10^{15} n/cm^2 sec in the reflector, this would result in gains of a factor of 12-18 in neutrons incident on the sample. For small samples it would be desirable to have the capability to decrease background with no loss of intensity from the sample by adjusting the effective source height.

It is also of interest to consider possible gains in neutrons delivered to the monochromator by using internally reflecting walls in a normal thermal beam tube installation. The importance of beam guides in transporting neutrons long distances (30-100 m) from a reactor is well known--we wish to

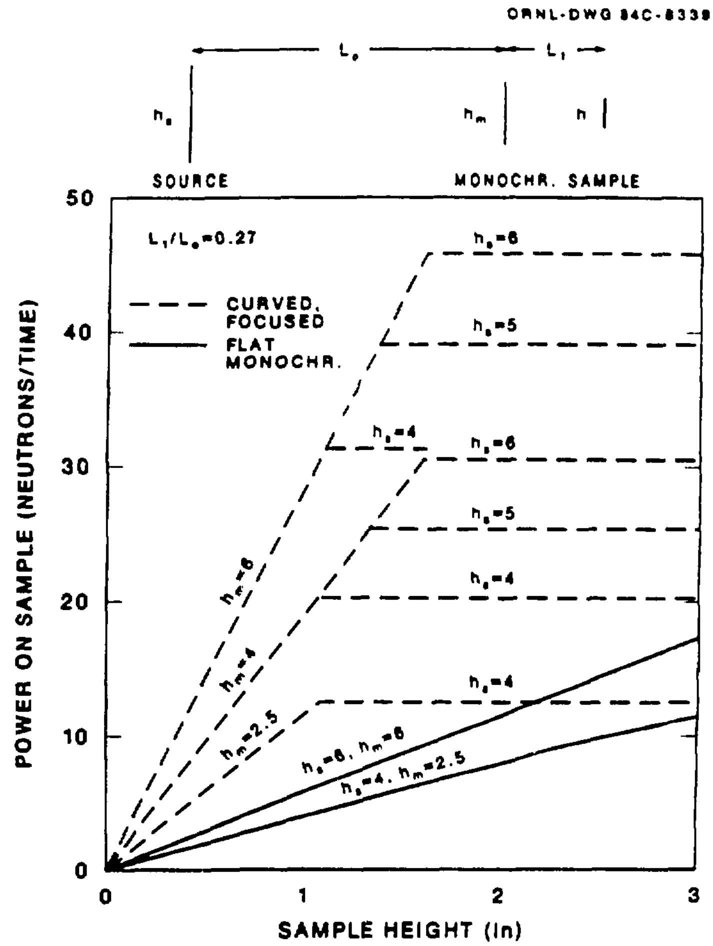

Fig. 3. Neutrons incident on sample as a function of sample height for various combinations of source height (h_s) and monochromator height (h_m). Dimensions are in inches. The proposed HFIR-II design would allow operation on the $h_m = 6$, $h_s = 6$ line. At present we are limited to $h_m = 2.5$, $h_s = 4$.

examine the question whether beam guide technology can be applied usefully for more modest distances (~ 7 m). Consider a beam tube of cross section d x d and length l. If the walls are non-reflecting the average intensity delivered at the outer end of the tube is proportional to the solid angle $(2\Theta_T)^2 = (d/L)^2$. If the walls are totally reflecting below a critical angle Θ_c the average intensity delivered is proportional to $(2\Theta_c)^2$ provided that $\Theta_c \gg \Theta_T$. In this limit the intensity gain is

$$G = (\Theta_c/\Theta_T)^2. \quad (1)$$

In the opposite limit ($\Theta_c \ll \Theta_T$) the gain must go to one. In the transition region ($\Theta_c \approx \Theta_T$) the correct result is not obvious. For off-axis positions at the entrance plane of the tube, the center of the angular range for direct transmission will not coincide with the center of the angular range for transmission by reflection. The total angular range of acceptance may thus be broader than either $2\Theta_c$ or $2\Theta_T$. By calculating this total angular acceptance, averaged over the entrance plane of the tube, as a function of Θ_c/Θ_T, the curve shown in Fig. 4 was obtained. Note that Eq. 1 is valid for $\Theta_c/\Theta_T > 2$.

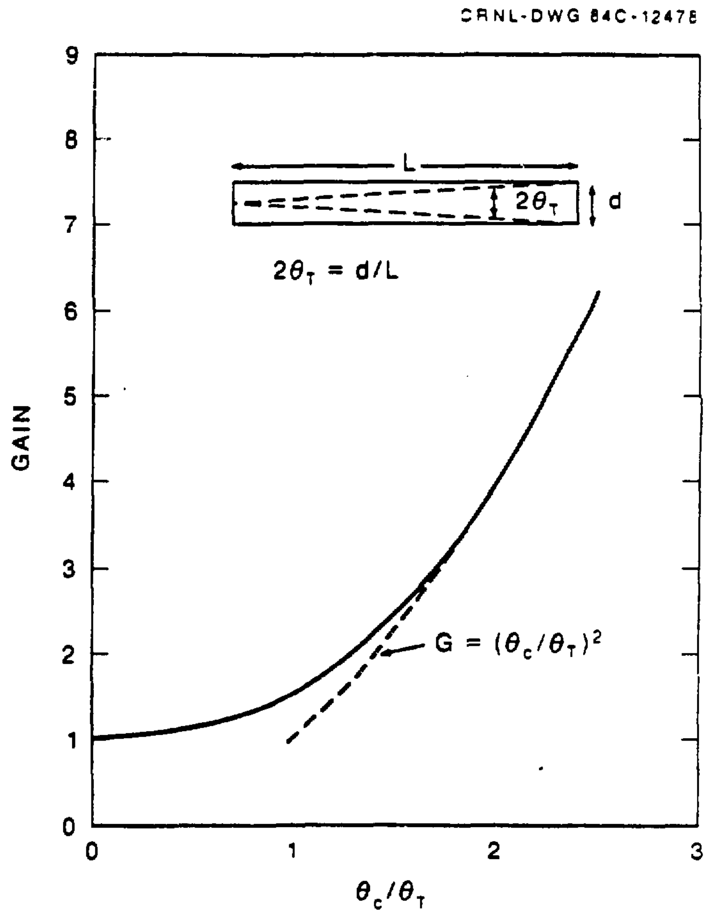

Fig. 4. The ratio (gain) of intensity delivered by a tube with totally reflecting walls to intensity for the same tube with non-reflecting walls. The critical angle for total reflection is Θ_c; the beam tube geometry (here assumed to have a square cross section) determines Θ_T.

The curve in Fig. 4 has been used to calculate the gain for a typical installation (d = 10 cm, L = 700 cm). In general, $\Theta_c = k\lambda$ so that the gain is dependent on the neutron wavelength. Table 2 gives values for k for various possible coating materials which might be used to produce the internally reflecting walls.

The results are shown in Fig. 5 for the three cases. The gains for Ni or ^{58}Ni are of questionable value except for the longer wavelengths. The

Table 2. Reflecting properties of various materials. $\Theta_c(rad) = k\lambda(Å)$

Material	k
Ni	$1.73\ 10^{-3}$
^{58}Ni	$2.05\ 10^{-3}$
Supermirror	$3.81\ 10^{-3}$

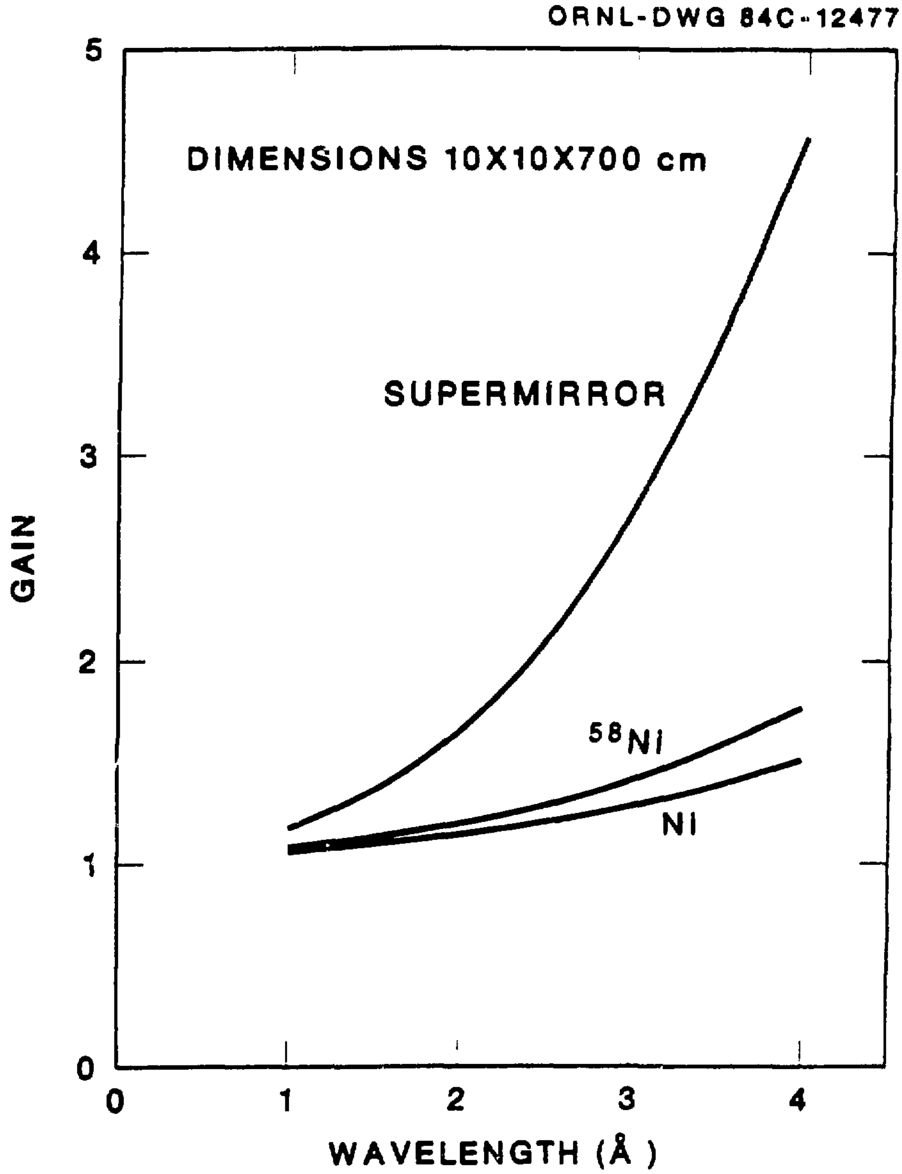

Fig. 5. Gain at a typical monochromator distance for reflecting beam tubes of various types as a function of neutron wavelength.

supermirror case is rather exciting--note that a gain of 2 could be obtained for the popular wavelength region around 2.5 Å. In an actual installation the associated effects on the angular divergence and uniformity of the exit neutron intensity should be assessed carefully. This result provides additional motivation for a strong program in supermirror development, such as has been proposed by Brookhaven National Laboratory.