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Some Preliminary Design Considerations for the ANS Reactor Cold Source*

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by

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Some Preliminary Design Considerations for the ANS Reactor Cold Source

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The Advanced Neutron Source (ANS) Reactor is a facility designed to provide the world's most intense steady state neutron source for neutron scattering research[1] with one of the major areas of research being that of cold neutron scattering. Cold neutrons are defined as neutrons that are in the wavelength band of 4 to 12 Å which corresponds approximately to the energy band 5×10^{-4} to 5×10^{-3} eV. For a research reactor operating at room temperature ~295 K and one in which the neutrons have achieved a nearly Maxwellian energy distribution, the number of neutrons available within the wavelength band of interest is approximately 6% of the total neutron population. This usually translates into a low intensity cold neutron beam of poor quality available for experiments. To enhance the fraction of cold neutrons for experimental use within the wavelength band of interest, a cold neutron source or moderating region is used to bring the neutrons into thermal equilibrium with a moderating material at low temperature.

The primary cold source moderating material considered for the ANS facility is liquid deuterium, operating at a temperature of approximately 20 K. Safety concerns related to the use of liquid deuterium as the cold source moderator have led to the investigation of isotopic liquid nitrogen-15 as a possible alternative moderator. Liquid nitrogen-15 has several desirable characteristics for a cold source moderating material[2]:

(a) it is a molecular liquid, so rotational levels are available for final thermalization at the low energy end of the spectrum;

(b) the first solid phase is plastic, so that rotational levels would remain available if a colder solid moderator were possible;

(c) it has good refrigeration characteristics;

(d) it is free of some safety problems inherent in most hydrogenous cold moderators; and

(e) it has a very low thermal neutron capture cross section $\sigma_a = 2.4 \times 10^{-5}$ barns.

Since the atomic mass and the temperature of the moderating material both influence the cold neutron energy spectrum, two unfavorable characteristics are:

(a) its atomic mass of 15 as compared to 2 for deuterium; and

(b) the temperature of its liquid range being 63-77 K versus 14-20 K for deuterium.

To investigate the performance of a possible nitrogen-15 versus a deuterium cold source, group gain factors are computed for each moderator using simple slab and spherical geometry calculational models. The slab geometry calculations allow one to examine the degree of neutron transmission and reflection. The calculational model consists of a one-dimensional slab with a vacuum boundary condition on the right and an isotropic flux of neutrons directed into the slab with a Maxwellian energy distribution at 293 K as the left boundary condition. A slab thickness of 20 cm is used for the nitrogen-15 moderator and a slab thickness of 15 cm is used for the deuterium moderator. These thicknesses were previously determined by transmission optimization calculations. The ideal situation, that of a moderator immersed within an isotropic and spatially uniform density flux of neutrons is investigated by the spherical geometry model. Spheres with diameters of 34, 42 and 50 cm are considered. The group gain factors computed are defined as

$$\text{Gain Factor}(g) = \frac{\text{neutron leakage in group } g \text{ (reflected or transmitted)}}{\text{number of source neutrons in group } g} .$$

The calculations are normalized to one incoming neutron and are performed using the ANISN[3] and DOT[4] transport codes.

A 15-group P_0 deuterium cross section data set was prepared from the ANSL-V[1,5] 39-group cross-section data library for the thermalization calculations. The thermal energy groups are flux weighted by a Maxwellian distribution at 20 K. A preliminary 15-group P_0 nitrogen-15 cross section set was generated from a theoretical estimate of the double differential scattering cross section[6] by using the cold neutron scattering model for homonuclear diatomic liquids by V. F. Sears[7,8] and the liquid nitrogen total structure measurements by Narten et al.[9] The nitrogen-15 15-group cross sections are flux weighted by a Maxwellian distribution at 65 K. The nitrogen-15 data set is quite preliminary as the cross section data have not been compared to experimental data. Both cross section sets contain neutron upscattering data. The upper and lower energy boundaries of the 15-group cross section set are 215 and .01 meV, respectively.

Displayed in Fig. 1 are the transmitted group gain factors plotted according to their midpoint wavelengths for the deuterium and nitrogen-15 cold source slabs. The results are broken down into two categories; the transmitted and reflected gain factors. For both categories as one goes to longer wavelengths, the deuterium gain factors become increasingly larger than the nitrogen-15 values. This difference in the gain factors is attributed to the difference in the temperature of the moderating materials (a colder moderator enhances the neutron fraction at longer wavelengths) and the difference in their atomic masses (neutron energy loss by elastic collisions is greater for lighter elements). Also, quite noticeable is that the reflected gain factors are larger than the transmitted values. This suggests that the reflection of neutrons and not transmission of neutrons is the dominant moderating mechanism for both materials. This is an important consideration in the design of the cold source, which is located within the D_2O reflector where there is a flux gradient in both the axial and radial directions. This will be further investigated in two-dimensional calculations.

Figure 2 displays the group gain factors for deuterium and nitrogen-15 spheres for the ideal situation of a spherical cold source immersed within an isotropic and spatially uniform density flux of thermalized neutrons. One notices a similar trend as in the slab geometry calculations; the deuterium gain factors become increasingly larger than the nitrogen-15 values as one goes to longer wavelengths. Also, one notices that the gain factors increase with sphere size though the increase is less for the same step increase in size.

As a brief summary, two areas concerned with the design of the ANS cold source have been investigated by simple one-dimensional calculations. The gain factors computed for a possible liquid nitrogen-15 cold source moderator are considerably below those computed for the much colder liquid deuterium moderator, as is reasonable considering the difference in moderator temperature. Nevertheless, nitrogen-15 does represent a viable option should safety related issues prohibit the use of deuterium as a moderating material. The slab geometry calculations have indicated that reflection of neutrons may be the dominant moderating mechanism and should be a consideration in the design of the cold source.

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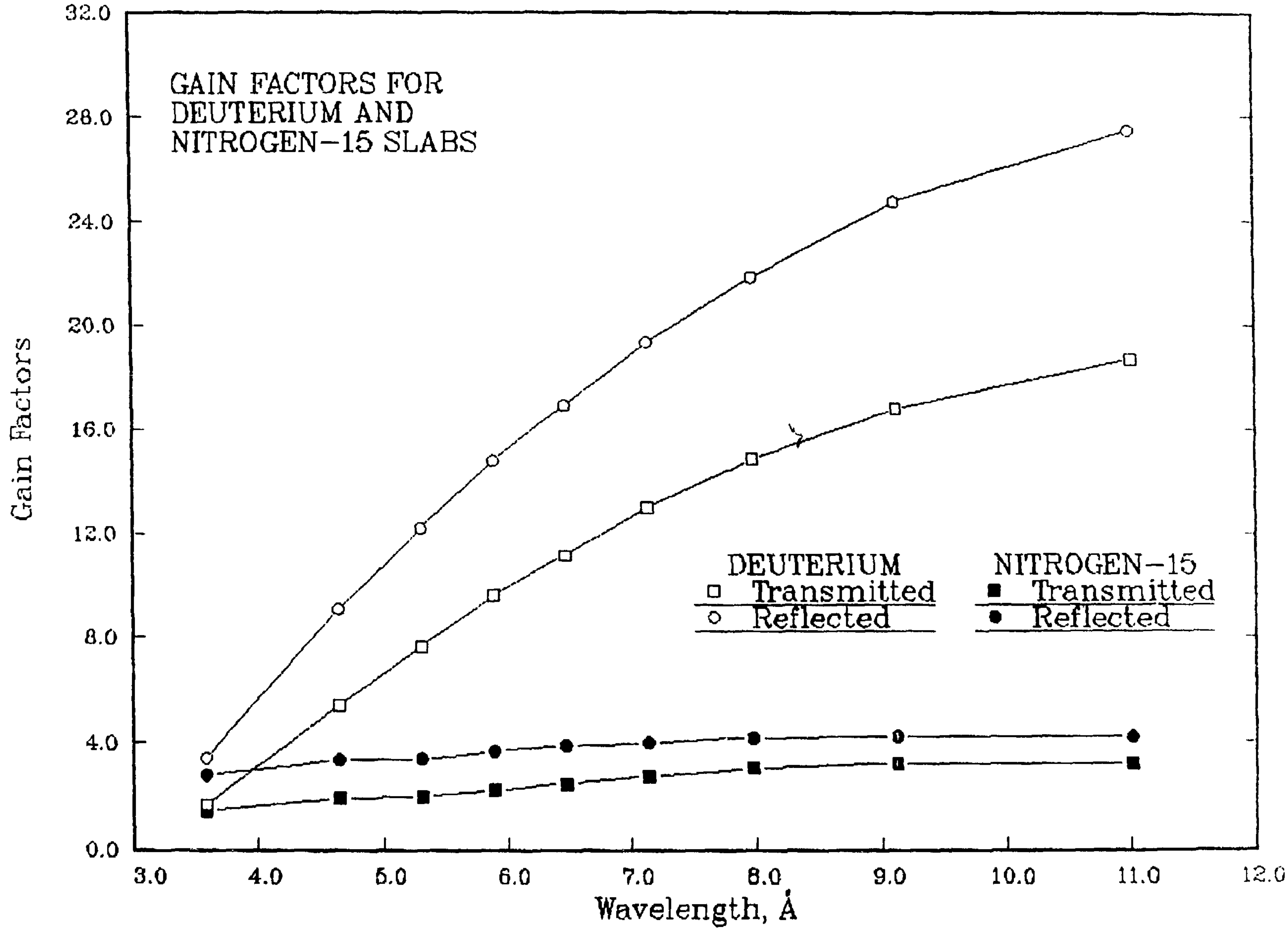
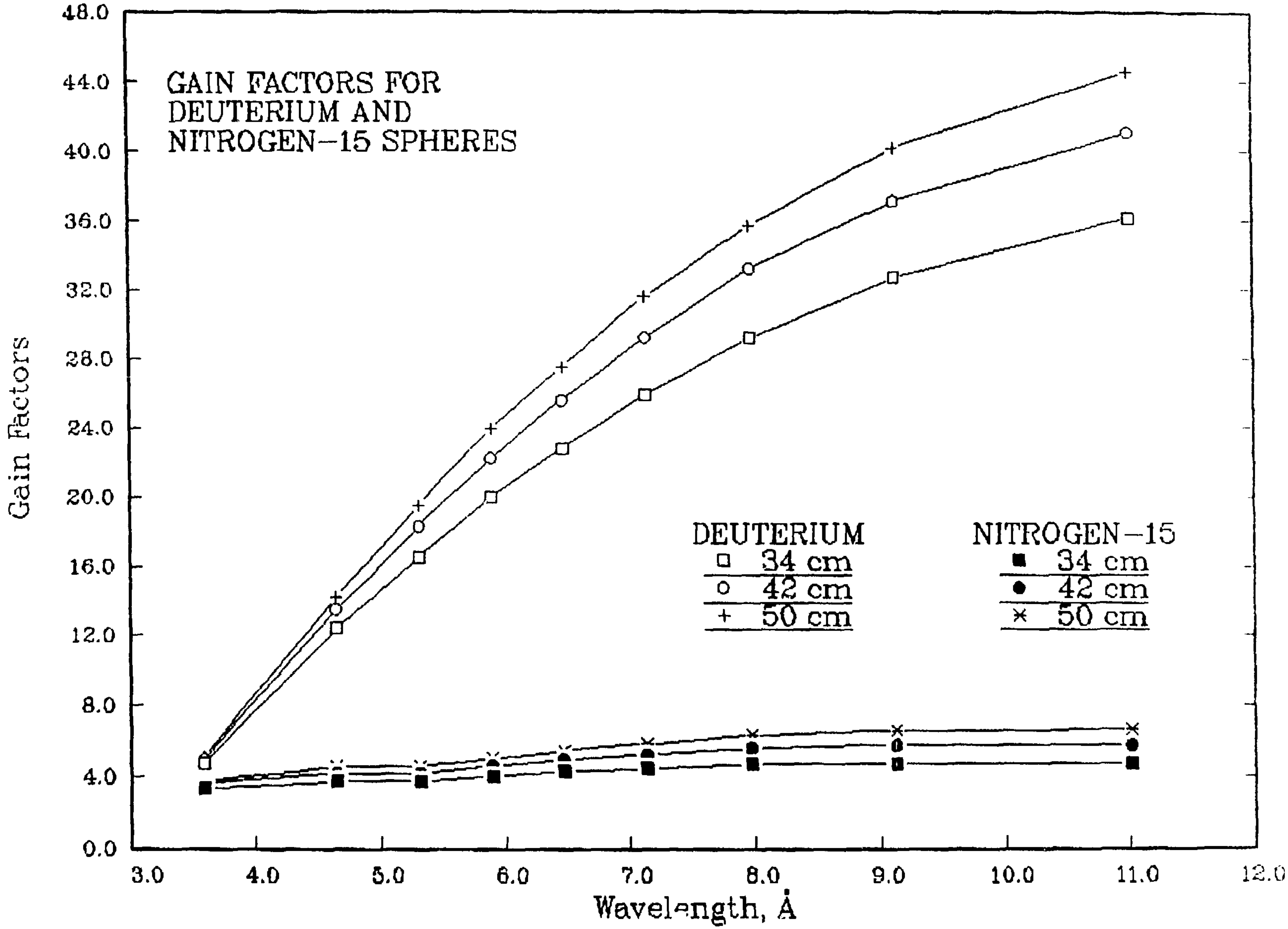
FIGURE CAPTIONS

Fig. 1. Gain factors for a liquid deuterium slab moderator of thickness 15 cm and for a liquid nitrogen-15 slab moderator of thickness 20 cm.

Fig. 2. Gain factors for liquid deuterium and liquid nitrogen-15 spherical moderators with diameters of 34, 42, and 50 cm.


GAIN FACTORS FOR
DEUTERIUM AND
NITROGEN−15 SLABS
Gain Factors
Wavelength, Å
DEUTERIUM
Transmitted
Reflected
NITROGEN−15
Transmitted
Reflected
0.0
4.0
8.0
12.0
16.0
20.0
24.0
28.0
32.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0



GAIN FACTORS FOR
DEUTERIUM AND
NITROGEN−15 SPHERES
DEUTERIUM
34 cm
42 cm
50 cm
NITROGEN−15
34 cm
42 cm
50 cm
Gain Factors
Wavelength, Å
0.0
4.0
8.0
12.0
16.0
20.0
24.0
28.0
32.0
36.0
40.0
44.0
48.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0