ICANS-VI

INTERNATIONAL COLLABORATION ON ADVANCED NEUTRON SOURCES

June 27 - July 2, 1982

HOW MUCH THERMAL NEUTRON FLUX IS GAINED USING DEUTERONS INSTEAD OF PROTONS?

G.S. Bauer, H.M. Conrad, K. Grünhagen and H. Spitzer
Institut für Festkörperforschung der KFA Jülich GmbH
W.Germany

G. Milleret
Labortoire National SATURNE, Saclay, France

ABSTRACT

The neutron leakage fluxes from hydrogeneous moderators have been measured as a function of the energy of protons and deuterons impinging on lead and depleted uranium targets. A gain in thermal neutron yields has been observed in any case using deuterons. The gains depend on both primary particle energies and target materials. The economic advantage employing deuterons instead of protons can be stated in two ways: firstly, using 850 MeV deuterons and a lead target the same thermal leakage flux is obtained as with 1100 MeV protons, or secondly, using 1100 MeV deuterons a flux increase of about 30% is gained. The figures for a uranium target are 900 MeV deuterons or 23% flux gain respectively.

HOW MUCH THERMAL NEUTRON FLUX IS GAINED USING DEUTERONS INSTEAD OF PROTONS?

G.S. Bauer, H.M. Conrad, K. Grünhagen and H. Spitzer
Institut für Festkörperforschung der KFA Jülich GmbH
W.Germany

G. Milleret
Labortoire National SATURNE, Saclay, France

1. INTRODUCTION

Loss of kinetic energy of charged particles due to ionization of matter penetrated by high energy ions are the reason for the very low neutron yields at particle energies below 100 MeV /Bartholomew, 1966/. Clearly, neutral particles cannot be produced with, or accelerated to, the high kinetic energies necessary for efficient spallation reactions. On the other hand, heavier nuclii containing neutrons can be used as vehicles for neutral projectiles. Although ionization losses may become very severe for multiply charged ions, numerical calculations by Barashenkov (1974) indicated that an appreciable gain in neutron yield may be obtained by using deuterons instead of protons (deuterons are stripped on impinging on matter giving two particles with half the kinetic energy each; binding energy of -2.2 MeV neglected).

As neutron production by spallation is a power consumptive, i.e. a costly procedure, each possibility for increasing its efficiency should be checked. For the German spallation project (SNQ project) this might mean a reduction in investment expenses and particularly in running costs if a lower-energy linac for deuterons could be envisaged. In order to improve the basis for this discussion we performed measurements of the thermal neutron leakage fluxes from hydrogeneous moderators in a target-moderator-reflector geometry as proposed for the SNQ project. We decided to measure the gains in thermal fluxes in realistic arrangements instead of determining the fast neutron yields from targets in order to be independent of any subsequent corrections and conversions.

2. EXPERIMENTAL

The experiments have been performed at the synchrotron of the Laboratoire National SATURNE. The set-up is the same as used in our former investigations and details are described elsewhere /Bauer et al., 1981c/. With the present measurements we used for the first time the actual H_2O-moderator planned for use in the SNQ, its size and shape (grooved surfaces!) being the result of our former studies /Bauer; 1981a, 1981b/. This moderator is shown in figure 1.

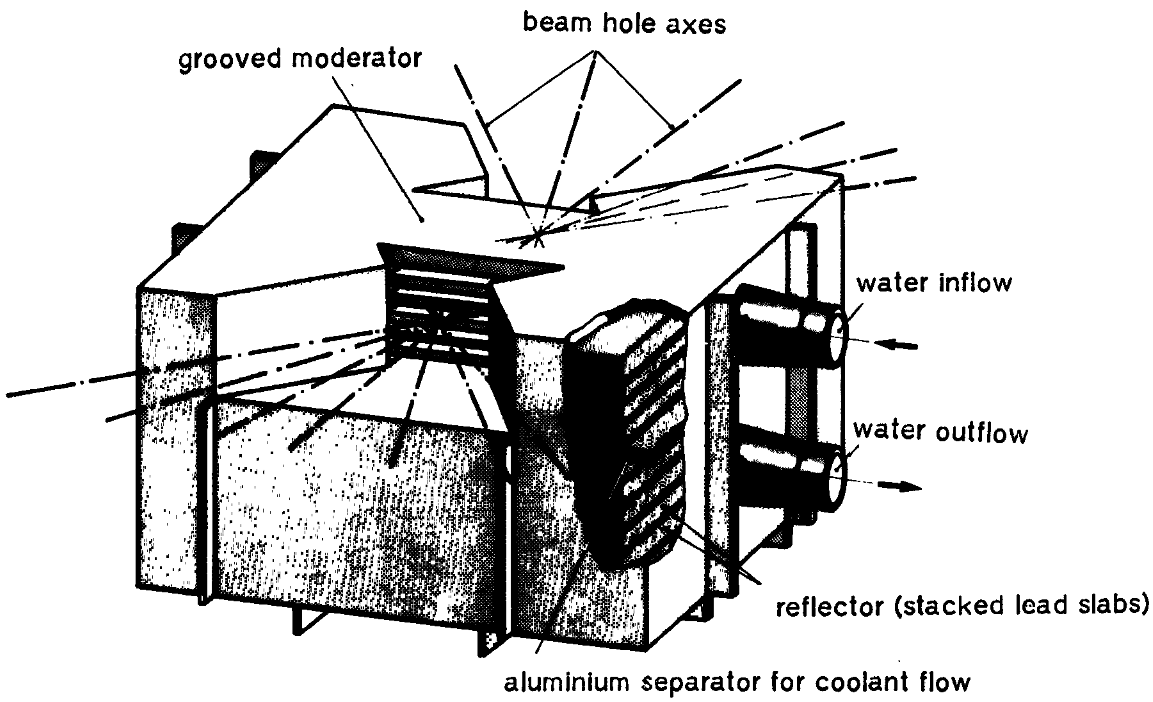

Fig. 1
Grooved-surface H_2O-moderator with lead reflector

The SNQ mock-up used for our measurements can be briefly characterized as follows: lead target with dimensions 10x50x75 cm^3 (height x width x depth), the H_2O-moderator with lead reflector, a graphite block of 40x60x60 cm^3 (simulating the D_2O-moderator) below the target and an overall lead shielding of about 50 cm thickness. The uranium target had the dimensions 10x45x50 cm^3.

The proton energies used were 400 MeV, 600 MeV, 750 MeV and 1100 MeV. With deuterons we utilized only the lower three values, 750 MeV being the highest energy which could be diverted into our experimental area. The absolute numbers of protons and deuterons impinging on our targets were determined by carbon activation in separate short calibration irradiations in which the counts simultaneously recorded with secondary emission chambers (SEC) and ionizations chambers (IC) were related to the activation results. In the actual experiments the SEC and IC counts were used as a measure of the number of the primary particles.

3. RESULTS AND DISCUSSION

Although we measured the gain of thermal neutrons emerging from hydrogeneous moderators in various configurations using deuterons instead of protons, the main emphasis in this paper will be on the SNQ target-moderator-reflector arrangement employing the proposed grooved-surface H_2O-moderator mentionned above. The results for reflected and unreflected polyethylene moderators both measured with lead and uranium targets are quoted only briefly.

Figure 2 shows the thermal neutron leakage fluxes from the H_2O-moderator with lead reflector, resulting from bombarding lead or depleted uranium targets with both protons and deuterons of various energies.

As mentionned in the caption of figure 2, the lines drawn through the experimental data points are guides to the eye only. The reader should keep in mind that the data of figure 2 do not exhi-

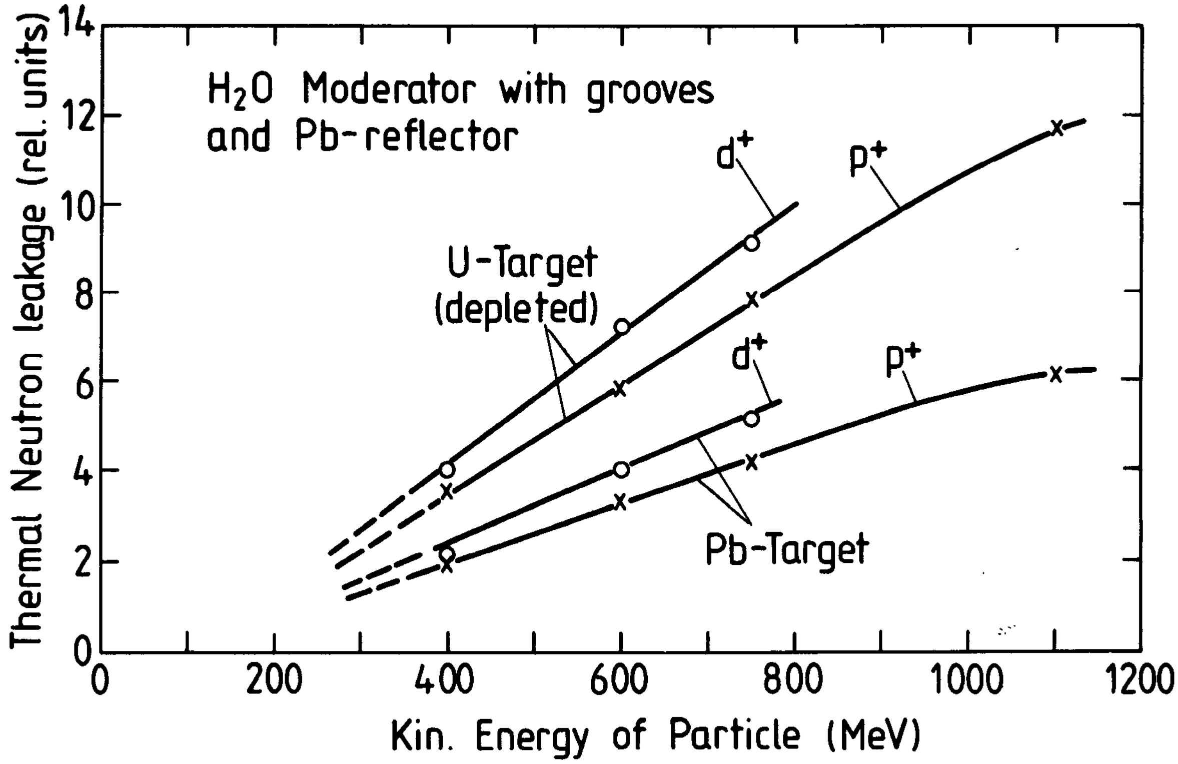

Fig. 2

Relative thermal neutron leakage measured from an H_2O-moderator for slab targets (10 cm high) of Pb and depleted U as a function of kinetic energy for protons and deuterons. The geometry was the same for all energies and for protons and deuterons. Curves are a guide to the eye only.

bit the total fast neutron yield as a function of energy as, for instance, given in the paper of Barashenkov /1974/. The plotted thermal neutron leakages represent the expected fluxes of a realistic target-moderator-reflector configuration. The data therefore contain physical parameters like target-moderator geometry, penetration depth of the primary protons or deuterons and coupling efficiency for fast neutrons from target into moderator. The increasing penetration depth of the primary particles with increasing kinetic energy in conjunction with the finite size of the moderator may explain the downward bending of the leakage curves for protons at higher energies. In fact the bending is less pronounced for the uranium target. This is consistent with the smaller penetration depth of protons in that material.

Despite the difficulties in expressing our experimental data in mathematical relations, as discussed so far, we may answer the following question without stressing our results too much. What is the kinetic energy of deuterons yielding the same thermal neutron flux per primary particle as do protons of 1100 MeV?

Inspection of figure 2 shows that only a slight (linear) extrapolation of the deuteron lines is necessary to see that 850 MeV deuterons on a lead target will yield the same thermal flux like 1100 MeV protons. For the uranium target we find that 900 MeV deuteron are sufficient to yield the same flux as 1100 MeV protons.

If we linearly extrapolate the deuteron lines to 1100 MeV, we can estimate the flux gain we would obtain in employing deuterons instead of protons. (This extended extrapolation appears to be justified because the deuterons are likely to have a shorter effective range in the target relative to protons.) Under this assumption the flux gain with 1100 MeV deuterons is found to be about 30% for a lead target and about 23% for a depleted uranium target.

Table 1 shows a comparison of the gains according to our experimental data for the lead target and the results of Barashenkov's /1974/ numerical calculations. Although Barashenkov calculated total fast neutron yields the comparison with our data is certainly justified for the lower energies, where minor coupling and penetration effects influence the proportionality of fast neutron yields and thermal leakages. A comparison with Barashenkov's uranium data is omitted because these results refer to natural uranium whereas we employed depleted uranium.

For the sake of completeness we have added table 2, in which the results for the other target-moderator-reflector configurations are listed. Most of these data may be of academic interest only.

E [MeV]	Theory [Barashenkov] (lead target) N_{d^+} / N_{p^+}	This experiment (lead target) Φ_{d^+} / Φ_{p^+}	This experiment (depleted uranium) Φ_{d^+} / Φ_{p^+}
400	1.11	1.10	1.13
600	1.18	1.22	1.24
750	1.16	1.23	1.16
1100	(1.13)	(1.30)	(1.23)
	extrapolated values		

Table 1: Comparison of numerical calculations /Barashenkov, 1974/ of fast neutron gain N_d+/N_p+ with experimental data for the thermal neutron leakage gain Φ_d+/Φ_p+ on changing from protons (p^+) to deuterons (d^+). The comparison is for a lead target. The column on the right are experimental values for a depleted uranium target.

E [MeV]	Φ_{d^+} / Φ_{p^+}			
	grooved polyethylene moderator			
	lead target		depleted uranium target	
	lead shielding no reflector	no reflector + shielding	lead shielding no reflector	no reflector + shielding
400	1.11	1.07	-	-
600	1.18	1.26	-	-
750	1.20	1.24	-	1.19

Table 2: Thermal neutron leakage gain factors for a grooved polyethylene moderator in several configurations. Dimensions of the moderator are 13.5x10x20 cm^3 with 1 cm wide and 6 cm deep grooves pointing toward the neutron beam tube.

4. CONCLUSION

It is obvious that a thorough discussion of the advantages and disadvantages of employing deuterons, even on the basis of our experimental results, is beyond the scope of this report since this would involve accelerator technology quite heavily. Moreover, not every aspect can be formulated as a quantitative argument, so the final decision will have to balance quantitative economic aspects and qualitative reasons. We shall only give a brief summary of the pros and cons. There are mainly two pros: Firstly, an 850 MeV deuteron linac has less than 70 % of the length of an 1100 MeV proton linac if we utilize the same rf-frequency. This reduces investment costs at about the same ratio. Secondly lowering the primary particle energy reduces the power consumption of the linac and thereby the running costs of the spallation source, which are the dominating part (> 50%) thereof.

The two essential cons are: Firstly, under the assumption of a fixed pre-accelarator (dc-accelerator) energy, deuterons would leave that injector part with lower velocity, whence shorter drift- tubes or lower rf-frequency for the Alvarez-linac were necessary. Both is unfavourable because of weaker beam focussing and worse economics respectively. This drawback may be circumvented utilizing an RFQ-structure instead of the electrostatic pre-accelerator, because these structures are expected to reach about 2 MeV. Secondly, deuterons produce activation due to d-d reactions already in the low-energy injector structures, a fact which might impede the operation. This latter disadvantage is certainly not easily transferrable into quantitative economic terms.

REFERENCES

V.S. Barashenkov, V.D. Toneev, and S.E. Chigrinov;
Atomnaya Énergiya, 37, 480 (1974) (engl. translation: Sov. J. Atomic Energy 37, 1256 (1975))

G.S. Bauer, J.P. Delahaye, H. Spitzer, A.D. Taylor, and K. Werner (1981 a)
"Relative Intensities and Time Structure of Thermal Neutron Leakage from Various Moderator-Decoupler Systems for a Spallation Neutron Source"
paper D2-3 in "ICANS V" pp. 417-444, G.S. Bauer and F. Filges, eds., report Jül-Conf-45, Kernforschungsanlage Jülich

G.S. Bauer, W.E. Fischer, F. Gompf, M. Küchle, W. Reichardt, and H. Spitzer (1981 b)
"Thermal Neutron Leakage and Time Structure Measured for Various Target-Moderator-Reflector Configurations for a Spallation Neutron Source"
paper D2-4 in "ICANS V" pp. 445-474, G.S. Bauer and D. Filges, eds., report Jül-Conf-45, Kernforschungsanlage Jülich

G.S. Bauer, H.M. Conrad, H. Spitzer, K. Friedrich, and G. Milleret (1981 c)
"Measurement of Time Structure and Thermal Neutron Spectra for Various Target-Moderator-Reflector Configurations of an Intensity-Modulated Spallation Neutron Source"
paper D2-5 in "ICANS V" pp. 475-488, G.S. Bauer and D. Filges, eds., report Jül-Conf-45, Kernforschungsanlage Jülich