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**PEAK FLUX MEASUREMENTS
OF THE LLL HIGH-INTENSITY 14-MeV NEUTRON SOURCE**

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Abstract

The high-intensity D-T neutron source in operation at LLL permits a close approach to the actual neutron-producing region. Peak flux values have been studied analytically and are seen to be strong functions of the spot size of the beam and the minimum distance of approach. Comparison of analytic and Monte Carlo calculations with experiments involving zirconium and sulphur discs

lead to inferred source spot diameters not larger than 1.0 cm and minimum spacing of 0.3 to 0.4 cm. Measurements show that for a readily attainable intensity of 2×10^{12} n/sec from a new target, a peak flux of 5.5×10^{11} n/cm²-sec can be realized. Further, a peak flux of 9×10^{11} n/cm²-sec is easily within the capabilities of the present facility for an intensity of 2×10^{12} n/sec.

Introduction

Neutrons arising from the D-T reaction are of particular interest to workers in the fields of nuclear weaponry and controlled thermonuclear reactors. More recently, consideration of fast neutrons as a possible modality for radiation therapy has focussed additional attention on accelerator systems as economical sources of such neutrons. This growing concern has prompted closer scrutiny of the LLL high-intensity 14-MeV generator.

The facility consists of a 500-keV, 10-mA deuteron accelerator (insulated-core transformer, or ICT) equipped with a beam transport system that allows D⁺ ions to strike a rotating target. The target is a copper-alloy disc that is coated on the inner surface with titanium impregnated with tritium. It is cooled efficiently by a thin layer of water sprayed against

the outer surface to rapidly dispel the 4 kW of beam power. (Failure to cool the target would lead to release of the tritium from the inner surface layer.)

The present study concentrates on one very attractive aspect of the target design. The flux to which a sample is exposed is a sensitive function of the spacing between the source and the sample and the dimensions of the source and the sample. A sample to be irradiated may be placed within 4 mm of the neutron source. The target disc is 1.0 mm thick, of which the titanium tritide (~ 4 mg/cm²) accounts for $\ll 0.1$ mm. The water layer is expected to occupy ~ 1.0 mm and the water spreader of stainless steel another 0.2 mm. The collimator constrains the source spot diameter to ≤ 1.6 cm.

The influence of geometry on the sample to be irradiated will first be examined through the development of conclusions based on a simple mathematical model. These predictions will then be compared with experiments involving

small samples of zirconium and sulphur placed close to the ICT target. Performance characteristics of the present arrangement will then be specified, with recommendations for ensuring and enhancing high fluence values.

Mathematical Model

One can gain a quantitative perspective of the factors which lead to enhanced neutron fluences in the immediate environment of the source, through examination of a simple model. Consider a neutron disc source of radius R_s , emitting neutrons uniformly and isotropically from the surface. We will consider initially a sample

to be irradiated of volume dV , and having a reaction mean-free-path λ . This sample is located on the axis of the source disc and is a distance Z from the disc center. To simplify the integration, take $dV \equiv da \cdot dZ$, with da parallel to the source plane.

For a source surface density of S_0 , the reaction rate in dV :

$$dI = \int_0^{R_s} (2\pi r dr S_0) \cdot \frac{da \cos \theta}{4\pi R^2} \cdot \frac{dZ}{\lambda \cos \theta},$$

$$\frac{dI}{dV} = \frac{S_0}{2\lambda} \int_0^{R_s} \frac{r dr}{R^2} = \frac{S_0}{2\lambda} \ln(\sec \theta_{\max}), \quad (1)$$

where:

$$\sec \theta_{\max} = \frac{(Z^2 + R_s^2)^{1/2}}{Z}.$$

The "flux" is explicitly $\lambda \frac{dI}{dV}$.

Incidentally, the current through the surface area da is readily calculated:

$$\begin{aligned} dF &= \int_0^{R_s} (2\pi r dr S_0) \cdot \frac{da \cos \theta}{4\pi R^2}, \\ \frac{dF}{da} &= \frac{S_0}{2} \int_0^{R_s} \frac{r \cos \theta dr}{R^2} \\ &= \frac{S_0}{2} (1 - \cos \theta_{\max}). \end{aligned} \quad (2)$$

One can show that $\lambda \frac{dI}{dV} > \frac{dF}{da}$ because $\lambda \frac{dI}{dV}$ is weighted by $(\cos \theta)^{-1}$ to account for the actual path length through dV . As $(R_s/Z) \rightarrow 0$, both expressions move to the form typical of a point source:

$$\ln(\sec \theta_{\max}) \xrightarrow{\theta_M \rightarrow 0} \frac{\theta_M^2}{2},$$

$$(1 - \cos \theta_{\max}) \xrightarrow{\theta_M \rightarrow 0} \frac{\theta_M^2}{2}.$$

Fig. 1. Dependence of current and flux along radiating disc axis as a function of disc radius R_s and separation distance Z . The quantity $F_{R_s,0}$ is the ratio of flux to that of a point source of equal intensity, while $G_{R_s,0}$ is the current ratio.

For easy application, it is sensible to divide dI/dV and dF/da by $\theta_M^2/2 \approx R_s^2/2Z^2$ so that the normalized forms, $F_{R_s,0}$ and $G_{R_s,0}$, respectively, approach unity in the limit as $\theta_{\max} \rightarrow 0$. These are plotted in Fig. 1 and may be directly interpreted as correction factors to be multiplied onto the reaction rate, or current, calculated on the basis of a source whose total strength is located at the position of the source disc center.

These same curves apply to the symmetric situation, in which the source is at a point and the receiver disc, spaced a distance Z from the point source, is circular with a radius R_s . The curves would apply to the average fluence and current over the receiver disc. The point source is assumed here to be on the axis of the receiver disc. The mathematical solution for this symmetric case

is found to be of the same form as the ones treated above.

If the irradiated sample, small compared to R_s and Z , is displaced transverse to the source axis, the flux will be altered. Such a situation would arise at the ICT facility if the source itself shifted transversely (within the allowable circular area 1.6 cm in diameter) during a run, or if the initial placement of the sample to be irradiated was faulty. The geometry considered here is sketched below:

The length AB is simply:

$$(\epsilon^2 + r^2 - 2\epsilon r \cos \theta)^{1/2},$$

which leads to

$$|R| = (Z^2 + \epsilon^2 + r^2 - 2\epsilon r \cos \theta)^{1/2}.$$

The absorption rate in the volume

$dv (= da dZ)$ is then:

$$dI = \int_{r=0}^{R_s} \int_{\theta=0}^{2\pi} \frac{S_0 r d\theta dr}{4\pi R^2} da \cos \xi \frac{dZ}{\lambda \cos \xi}$$

$$\begin{aligned} \frac{dI}{dV} &= \frac{S_0}{4\pi\lambda} \int_0^{R_s} \int_0^{2\pi} \frac{r d\theta dr}{R^2} \\ &= \frac{S_0}{4\pi\lambda} \int_0^{R_s} \int_0^{2\pi} \frac{r d\theta dr}{Z^2 + \epsilon^2 + r^2 - 2\epsilon r \cos \theta}. \end{aligned}$$

Straightforward integration yields:

$$\begin{aligned} \frac{dI}{dV} &= \frac{S_0}{4\lambda} \\ &\times \ln \left\{ \frac{Z^2 + R_s^2 - \epsilon^2 + [(Z^2 + R_s^2 - \epsilon^2)^2 + 4\epsilon^2 Z^2]^{1/2}}{2Z^2} \right\}. \end{aligned} \quad (3)$$

When $\epsilon = 0$, the expression reduces to $[S_0 \ln (\sec \theta_{\max})]/2\lambda$, as we saw earlier.

For convenience, we will normalize the lengthy expression above:

$$H_{R_s, Z, \epsilon} \equiv \frac{(dI/dV)}{(dI/dV)_{\epsilon=0}}. \quad (4)$$

The product $F_{R_s, 0} \times H_{R_s, Z, \epsilon}$ gives then the degree to which the irradiation of a tiny sample is degraded because of the finite source size (i.e. $F_{R_s, 0}$) and displacement of the sample from the source axis (i.e. $H_{R_s, Z, \epsilon}$).

Figure 2 illustrates the behavior of the function $H_{R_s, Z, \epsilon}$ as a function of relative transverse displacement ϵ/R_s . It is quite

Fig. 2. Effect of displacement of the sample by a distance ϵ transverse to the axis of the source disc.

clear that the greatest deviation from unity of the function occurs for situations involving close relative proximity to the radiating disc (i.e. $Z/R_s < 1$) along with large transverse displacements (i.e. $\epsilon/R_s > 1$). A more general solution of the problem has been discussed by Smith and Storm.¹ They considered a disc radiating into an absorbing medium and solutions of the off-axis receiver problem. The zero-absorption case discussed here was not illustrated in that work, and is seen on comparison to be consistent for the two common cases $Z/R_s = 0.25$ and 1.0 . The absorbing medium acts, in the case of $Z/R_s \approx 0.25$, to make $H_{R_s, Z, \epsilon}$ more

like the step function: $H = 1$, $\epsilon/R_s < 1$; $H = 0$, $\epsilon/R_s > 1$. For $Z/R_s = 1$, the trend is the same but much less dramatic.

Finally we treat the geometry which involves a circular source disc and a circular receiver disc, with a common axis and with centers separated by a distance Z . Simple numerical integration based on Fig. 2, with proper weighting according to receiver radial area increments, yields Fig. 3. This set of curves joins the others to serve to guide the design of experiments where factors such as peak fluence and uniformity of irradiation are of importance. We will now consider the experimental data which was gathered.

Fig. 3. Effect of finite size of receiver disc as a function of spacing and relative size of receiver.

Experimental Procedure

On September 21, 1972, a series of irradiations were made at the ICT facility to determine the maximum flux attainable. Discs of zirconium and sulphur were activated in separate runs in a stacked arrangement where each disc was positioned along the beam line with its plane parallel to the neutron-source plane.

The neutron source itself has been described in detail elsewhere.^{2,3} A D^+ beam of up to 10 mA is accelerated to an energy of 400 keV and strikes the tritium target. A layer of titanium vapor plated to a copper-alloy backing is previously exposed to tritium gas and the gas reacts to form a stable solid target material.

The target is depicted in Fig. 4. The beam is collimated to strike a small circular spot, no larger than 1.6 cm in diameter, on the target. To prevent excessive heating of the TiT, the target rotates and is water cooled on the opposite side of the copper alloy backing. (The alloy, called Amzirc, contains 0.15% Zr and is manufactured by American Metal Climax, Inc.)*

*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Atomic Energy Commission to the exclusion of others that may be suitable.

Fig. 4. Target system layout.

Of importance to the present study are the thicknesses of materials between the neutron source itself and the object to be irradiated, which limit the minimum distance of approach. The TiT is $\sim 4 \text{ mg/cm}^2$ and so is of negligible thickness (i.e. $< 0.1 \text{ mm}$). The target backing is 1.0 mm thick, and is in contact with a water layer of undetermined thickness. Design considerations would suggest a coolant thickness of at least 0.3 mm . The stainless-steel spreader is only 0.2 mm thick, and the steel cover to the water catch cage is 0.1 mm . It follows that the minimum thickness for all of these materials is 1.6 mm . What can affect this is variation in the contour of the water spreader and, perhaps more important, the thickness of the water layer itself.

The circular discs to be irradiated were packaged in a low-mass stacked arrangement where, in each exposure, the discs shared a common axis that coincided with the axis of the ion beam. To determine the center of the beam spot, a special film (Kodak Pathe No. LR 115) sensitive to recoiling heavy charged particles was emplaced directly against the catch cage cover. Subsequent development of the film in NaOH solution (10% by weight, at 68°C) for a few minutes afforded a rapid, convenient way to determine the effective center of the source.

Five disc packages were irradiated. The first two incorporated zirconium discs of 0.952 cm diameter and individual masses of 225 mg . The second two packages consisted of sulphur discs, 0.18 cm thick and 1.22 cm in diameter. The final package was composed of three zirconium discs of 2.42 cm diameter and one smaller disc like those in the first two exposures,

pressed together with a common axis. The masses of the larger zirconium discs were each in the range of 1.432 to 1.439 g . Table 1 lists the position of each disc with respect to the front face of each stack.

Table 1. Positions of centers of irradiated discs (cm from front face of stack).

Position	Package and material				
	I Zr	II Zr	III S	IV S	V Zr
1	0.025	0.025	0.09	0.09	0.025
2	0.076		0.28		0.076
3	0.455		0.48		0.126
4	0.94		1.00		0.176
5	1.97	2.045	1.91	2.00	
6	2.95		3.02		
7	4.00		4.00		
8	4.99	5.025	4.97	4.98	

These dimensions are accurate to $\pm 0.02 \text{ cm}$ with respect to the front plane of the stack. Certainly the positions of the discs close to the front face plane are more accurately known, but we will see below that the uncertainty in the minimum spacing between the source plane and the plane of the package front face exceeds $\pm 0.02 \text{ cm}$.

Two packages of small zirconium discs and two of sulphur discs provide empirical means of determining the extent to which self-shielding by the discs closer to the source affected the activities of the more distant discs. For zirconium, the total cross section, σ_t , is $\sim 3.75 \times 10^{-24} \text{ cm}^2$ at $E_n = 15 \text{ MeV}$.⁴ Each disc is 0.313 g/cm^2 thick, which implies a probability of interaction of 0.8% per disc. If any interaction removes the neutron, then the activities in zirconium discs at the most distant stations will differ by $\sim 4\%$ for the

same integrated flux. For sulphur, σ_t is $-1.92 \times 10^{-24} \text{ cm}^2$ at $E_n = 15 \text{ MeV}$,⁵ and so for a disc thickness of 0.18 cm the probability of interaction per disc is 1.3%. Here also, comparison of the two sulphur disc packages will provide an empirical value for self-shielding.

All runs were monitored by a pair of proton-recoil detectors of standard design.⁶ These were positioned at an

angle of 112° with respect to the beam, and the distance from the source to the front face of each detector was 120 cm. The absolute accuracy of each is thought to be $\pm 5\%$. Independent calibrations are available through the activation levels of the zirconium and sulphur discs, with accuracy determined primarily by the experimental uncertainties of the $^{90}\text{Zr}(n,2n)$ and $^{32}\text{S}(n,p)$ cross sections.

Experimental Results

Each of the five exposures was made for a preselected number of counts of the proton recoil counter. In our counter No. 2, 1.80×10^5 counts corresponded to 2.99×10^{13} neutrons/steradian in the forward direction, while counter No. 3 registered 2.02×10^5 counts, or 3.20 neutrons/steradian in the forward direction. Each exposure was about 5 min long, since the source strength in these runs was $1.3 \times 10^{12} \text{ n/sec}$, reflecting the age of the tritium source.

Table 2 lists the integrated flux for each disc. Calibrated disc-counting facilities permitted the determination of the integrated flux in all cases, with the following adopted cross sections:⁷

$$\sigma(^{90}\text{Zr}(n,2n)^{90}\text{Y})_{15.1 \text{ MeV}}$$

$$= 0.90 \times 10^{-24} \text{ cm}^2$$

$$\sigma(^{32}\text{S}(n,p)^{32}\text{P})_{15.1 \text{ MeV}}$$

$$= 0.20 \times 10^{-24} \text{ cm}^2.$$

The position designations are identified in Table 1. Standard procedures were followed in the flux determination, such

as correction for decay of samples during the interim period. (The recoil-counter data were not used here, but afford a comparison below.)

Table 2. Neutron fluence inferred from Zr and S activities (10^{13} n/cm^2).

Position	Package and material				
	I Zr	II Zr	III S	IV S	V Zr
1	8.51	9.52	7.69	7.73	3.38
2	7.25		5.94		3.06
3	3.08		3.50		2.75
4	1.46		1.57		4.48
5	0.48	0.488	0.564	0.551	
6	0.246		0.269		
7	0.143		0.158		
8	0.0948	0.0932	0.106	0.106	

The discs at position 8 are sufficiently far so that the $1/R^2$ approximation may be applied for a quick consistency check. The neutron fluence values there, as determined from the proton recoil counters, are 0.103×10^{13} and $0.110 \times 10^{13} \text{ n/cm}^2$, if a spacing between the source and front face of the disc package of 0.4 cm is assumed. This latter increment, we recall, is at least $\sim 0.2 \text{ cm}$, but it can be

larger if the coolant water displaces the spreader outward. The sulphur values agree well with the counter values, but the zirconium values are ~12% below the counter values. Such a large discrepancy may suggest that the $^{90}\text{Zr}(n,2n)$ cross-section at $E_n = 15.1$ MeV is $\sim 0.88 \times 0.90$, or $0.79 \times 10^{-24} \text{ cm}^2$, but this experiment was not performed with sufficient care to indict the $^{90}\text{Zr}(n,2n)$ measurements. Rather, what we are after is the geometric character of the neutron source itself, to be inferred from the disc activities.

Another quantity immediately inferred from Table 2 is the equivalent minimum distance of approach, found by comparing the activities of the nearest and farthest discs and equating their ratio to the inverse ratio of the squares of their distances. For the first two zirconium packages, the effective minimum distance is ~ 0.57 cm for package I and ~ 0.54 cm for package II. For both of the sulphur packages, we find a value of 0.63 cm, which is larger than the zirconium values because the discs are thicker (i.e. 1.8 mm compared with 0.5 mm).

Careful comparison of the pairs of packages should reveal any disc self-shielding, since one member of each pair contains eight discs while the other contains three. What we were not able to control from one run to the next was the spacing between the source and the forward face of the disc package ($\Delta Z = Z_2$). It appears from Table 2 that package II was closer to the source than package I. If one uses the fluence values from package I as a guide and assumes Z_2 (package I) = 0.4 cm, then Z_2 (package II) = 0.36 cm.

With this latter value, the inferred self-shielding correction at the most distant station is negligible (i.e. 1.6%, in the opposite direction). Recall from our earlier discussion that if the total neutron cross section were effective in removing neutrons, a 4% self-shielding would be noted here.

A more defensible approach to self-shielding for our purposes is to refer to the compilation of pulsed-sphere data⁸ and note that neutron removal from its initial high energy is estimated with reasonable accuracy by taking about half of the total cross section. This would lead to a 2% self-shielding correction for the most distant zirconium disc.

For the sulphur pair, comparison of the data reveals no self-shielding, although by the above argument, approximately a 3% maximum self-shielding effect should be noted. We will defer discussion of the self-shielding issue to a later point in the paper.

In package V, the larger zirconium discs register a lower fluence than the smaller discs do at the same locations. To properly interpret the activity ratio of the large and small discs at the same spacing, it was necessary to refer to the activity of the fourth disc in package V, a small disc, and infer Z_2 (package V) from that data. If Z_2 (package I) = 0.4 cm, then what followed was Z_2 (package V) = 0.52 cm. The ratio of total disc activity of the large zirconium disc to that of a small disc, with $Z_2 = 0.4$ cm in common, is found by extrapolation to be 2.82. (This may be compared to the disc mass ratio of 6.37.)

Analysis of Data

Primary attention will be given the zirconium data, because the zirconium discs were thinner than the sulphur discs, and also because zirconium discs of two sizes were employed. The ratio of activities of the large and small zirconium discs is sensitive to the diameter of the neutron source, and this will be treated first.

Recall again that the source spot is limited to a circular region of 1.6 cm diameter. However, the beam from the accelerator may be focussed by adjustment of a quadrupole magnet. Since the autoradiographs were not developed in a systematic manner, comparisons between runs could not be made, but the general impression suggested a source disc diameter of ~1.0 cm.

The curves developed earlier in this work should be immediately applicable if two issues were found to be trivial. First, if the intervening medium were nonabsorbing, then the model is applicable. This is seen to be so by virtue of the small amount of mass between source and receiver. In fact, the self-shielding issue we discussed earlier dealt explicitly with intervening absorber material.

Secondly, one observes that the $^{90}\text{Zr}(n,2n)$ cross section, σ_{Zr} , is unfortunately highly variable in the $E_n = 15$ MeV range. Neutrons leaving the source at nonforward angles will be of less energy. Although their chord lengths in the disc will be greater than the thickness of the disc, the zirconium cross section will be lower and so the role of the oblique neutrons will be suppressed.

To deal more correctly with the variability of the σ_{Zr} , a series of TART⁹

Monte Carlo calculations was run, treating the geometry under discussion. Since the σ_{Zr} aspect was expected to be of small consequence, the Monte Carlos were run rapidly by simply tallying (a) the number of entries of neutrons into a disc, and (b) the total chord length within the disc. The ratio of these two values should be $\overline{\cos \theta}/\Delta x$, where Δx is the disc thickness. With $\overline{\cos \theta}$ inferred, one can immediately¹⁰ determine the corresponding average neutron energy and then the σ_{Zr} .

The Monte Carlo calculations grouped the events of interest within three energy bins so that correction for the σ_{Zr} effect could be made with reasonable care. For the larger zirconium discs the effect was as much as 12%. What we found was a family of paired values for Z_2 and R_s (where $Z_2 \equiv$ minimum spacing between source and front face of the disc package and $R_s \equiv$ the source radius). Two acceptable pairs were:

$$(Z_2 = 0.3 \text{ cm}, R_s = 0.5 \text{ cm})$$

and

$$(Z_2 = 0.4 \text{ cm}, R_s = 0.33 \text{ cm}).$$

Since problems had already been run at (0.3, 0.5) and (0.4, 0.3), which treated the smaller zirconium discs at all experimental stations, these were compared. Figures 5 and 6 illustrate the comparison between experiment and calculation of the product of disc activity and Z^2 versus axial distance. The Monte Carlo calculations were normalized to unity as $Z \rightarrow \infty$, and the experimental data (with no self-shielding correction) were normalized with the theoretical curve as a guide.

Fig. 5. Product of zirconium disc activity and Z^2 as a function of Z , the axial separation between the ICT source and the disc. Minimum distance between source and disc surface, $Z_2 = 0.3$ cm. Source radius, $R_s = 0.5$ cm.

The better fit is clearly
($Z_2 = 0.4$ cm, $R_s = 0.3$ cm).

A reasonable self-shielding adjustment would result in a ~2% increase in activity for the more distant discs. Renormalization would then drop the activities of the discs closer to the source by $\leq 2\%$. The agreement for the (0.4 cm, 0.3 cm) pair would persist over the other case. Another equivalence is with respect to the minimum distance, Z_2 . Assumption of an overall self-shielding effect of 2% would suggest a reduction in Z_2 of 0.25 mm.

It is indeed gratifying to observe excellent agreement between the observed activity and that calculated. We also begin to see clearly the importance of close approach to the neutron source to achieve highest flux. However, the non-point-source aspect becomes influential as $Z \rightarrow R_s$. When $Z/R_s = 1$, Fig. 6 shows the flux to be ~0.5 of that inferred by the simple Z^2 dependence.

The sulphur data were examined in a similar manner, relying this time on the mathematical model developed earlier in this report. In the case of sulphur, the

Fig. 6. Product of zirconium disc activity and Z^2 as a function of Z , the axial separation between the ICT source and the disc. Minimum distance between source and disc surface, $Z_2 = 0.4$ cm. Source radius, $R_S = 0.3$ cm.

$\sigma(^{32}\text{S}(n,p))$ decreases with energy, but not quite as rapidly as $\sigma(^{90}\text{Zr}(n,2n))$ increases with energy. The corrections derived from the zirconium study were scaled in accordance with the sign and magnitude of $(d\sigma/dE_n)$ and applied to the sulphur calculations. In the present case, one additional correction, a small one, was made to account for the slight anisotropy in the angular distribution of the neutron source. This was considered implicitly in the Monte Carlo calculations for zirconium.

Figure 7 illustrates the greater difficulty in fitting the sulphur data throughout the range. With a choice of ($R_S = 0.5$ cm, $Z = 0.25$ cm), the fit is excellent except for the disc nearest the source. The mathematical model assumes a receiver disc of infinitesimal thickness, while the sulphur discs are actually 0.18 cm thick; this might account for the discrepancy. The unusually rapid falloff of the curve as Z decreases is quite at variance both with the findings from the

zirconium data and with the model, and so suggests a systematic error in the

sulphur study—perhaps in the spacing determination.

Fig. 7. Product of sulphur disc activity and Z^2 as a function of Z , the axial separation between the ICT source and the disc. Minimum distance between source and disc surface, $Z_2 = 0.25$ cm. Source radius, $R_s = 0.5$ cm.

Conclusions and Recommendations

A simple model has been developed to apply to the ICT intense neutron source, and it has been compared favorably with data from experiments employing zirconium and sulphur discs in close proximity to the source. Minimum distances between

the actual source and receiver-disc face have been found, through comparison to analytic and Monte Carlo predictions, to range between 0.25 cm and 0.4 cm. The large variation suggests that the minimum spacing is not constant from run to run

and may be affected by water flow conditions. A simple alteration of the water-spreader support member is recommended to restrict motion of the spreader.

The experimental data showed clearly that for a total neutron production rate of 2×10^{12} n/sec, the closest zirconium disc would receive 5.5×10^{11} n/cm²-sec. The mathematical model showed further that if one can close the spacing by an additional 0.1 cm, the flux would rise by a factor of 1.3. A small receiver disc

(e.g. $R_r \leq 0.2$ cm) would further raise the flux value by a factor of ~1.2. Peak flux levels of $\sim 9 \times 10^{11}$ n/cm²-sec are easily within the capabilities of the present ICT facility when a new target is installed.

For studies such as those dealing with radiation damage, it is important when aiming for maximum damage to place small, thin samples as close to the source as possible. For the present configuration, disc diameters less than 0.5 cm and thicknesses less than 0.1 cm are recommended.

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