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STATUS OF PULSED SPALLATION NEUTRON SOURCE TARGET WORK AT BROOKHAVEN NATIONAL LABORATORY

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ABSTRACT

This paper outlines work carried out at BNL on the Pulsed Spallation Neutron Source (PSNS) target, since the ICANS-XII meeting. A target, reflector, and moderator assembly was designed consistent with a 1.25 GeV proton beam energy. This target consisted of two modules containing randomly packed tungsten spheres and one flux trap. In addition, a study was carried out of the variation of neutron pulse length with proton pulse length for various reflector/pre-moderator configurations. It was found that:

- The amplitude of the neutron pulses increases with decreasing proton pulse length,
- Long proton pulses overlap the neutron pulse developing in the moderator, while shorter proton pulses are complete before the neutron pulse develops in the moderator
- Reflector/pre-moderators which slow neutrons by inelastic scattering result in neutron pulses which are narrower, and have shorter tails.

1. Introduction

A pulsed spallation neutron source (PSNS) study has been undertaken at Brookhaven National Laboratory (BNL) over the past two years. The results of this study have been outlined in a report$^{(1)}$, and have been reported on at the ICANS-XII meeting $^{(2)}$. The parameters of this study were as follows:

- Average power of the proton beam 5MW
- Proton energy 3.6 GeV
- Two target stations operating at 10 Hz and 50 Hz
- Proton pulse width 1.2 μs.

The target associated with this design consisted of a three section/two flux trap arrangement. Due to the high proton energy three separate target sections could be used. "Wing", "back scatter", and "flux trap" moderator arrangements were employed in this target, making sixteen beam tubes possible. The neutron production volumes are surrounded by a beryllium reflector.

Keywords: Particle Bed Target, Lead Fluoride Reflector, Pulse Length

In this paper a target arrangement operating with a 1.25 GeV proton beam will be outlined. This proton energy is consistent with an accelerator system which consists of an accumulator ring rather than a synchrotron ring following the LINAC. In addition, a study of the dependence of moderator neutron pulse length as a function of reflector type and proton pulse length will be outlined. This study will be carried out on a simple target arrangement, rather than the more realistic targets described above.

2. Target Consistent with 1.25 GeV Proton Beam

The reduced range of 1.25 GeV protons implies a target which consists of two elements and one flux trap. The target elements consist of tungsten in the form of particles cooled by heavy water. The coolant flows at right angles to the direction of the proton beam through the particle bed. Two porous walls (frits) and four solid walls contain each of the particle beds. Two of the solid walls are in the proton beam, and are cooled on one side of the particle coolant. The frits separate the particle beds from inlet and outlet plena. The coolant flows along the inlet plenum, through the inlet frit, through the particle bed, and out the outlet frit and outlet plenum. Due to the extremely high heat transfer area per unit volume of the particle bed it is possible to remove well in excess of 3MW/L from the bed. Experimental results (3) have shown that it is possible to remove 3MW/L from a water cooled particle bed at ambient pressure before coolant boiling commences. Thus, with a moderate amount of system pressurization it should be possible to remove all the heat deposited in the bed. Furthermore, since the bed will be a tightly packed (no relative motion between particles), random arrangement of spheres, it is expected that the void fraction will be approximately 35%. Thus the average tungsten density in the target will be ~ 12.5 gm/cc. In order to minimize the pressure drop across the bed, the bed cross section will be rectangular with the flow traversing the shortest distance. The tungsten sphere OD was determined by the following four requirements:

- Increasing the OD will reduce the pressure drop
- Decreasing the OD will increase the area per unit volume, and thus heat removal ability
- Decreasing the OD will reduce the effect of thermal-mechanical induced shock stress enhancement
- The bed thickness in the direction of the coolant flow should be greater than 10 - 15 particle diameters, to avoid transients in the average particle bed void distribution.

Based on the above four requirements a particle OD of 2 mm has been chosen. This particle size results in an acceptable pressure drop, thermal performance, and essentially no stress enhancement due to thermal-mechanical shock.

All material structures of the target are of Inconel. This material has been used as window material at LAMPF, and shown to withstand substantial radiation exposures without unacceptable loss of integrity. An alternate material of construction with a low thermal expansion coefficient is also being considered. Since the thermal stress is proportional to the coefficient, a low cyclic stress would be implied. The target modules are surrounded by a beryllium neutron pre-moderator and multiplier zone 5 cm thick. This zone consists of beryllium spheres and is cooled by heavy water. The beryllium thus has a density of ~.73gm/cc and the heavy water density is ~.35 gm/cc. Finally, both light water and liquid hydrogen moderators are considered. It is expected that these moderators will yield peak neutron fluxes in the thermal range (~ 0.0253 eV) and the cryogenic range (~0.004 eV). Currently no poisoning and de-coupling of the moderators has been investigated.

3. Proton Pulse Length Implications

In this section the effect of the proton pulse length and reflector type on the moderator neutron pulse length and relative amplitude will be outlined. In order to carry out this study a simple target arrangement will be considered. It will consist of the following components:

- Cylindrical tungsten heavy metal target 15cm OD x 100-cm L
- Cylindrical reflectors surrounding tungsten 50cm ODx100cm L
- Two moderators (light water and liquid hydrogen) embedded in the reflector

The proton energy in all cases will be 2 GeV. Gaussian pulse shapes in time, with widths varying from 1.2 (-6) s - 1.0 (-3) s are assumed. The four different reflector/pre-moderators assessed in this study are:

- Lead Fluoride (PbF_2)
- Beryllium Fluoride (BeF_2)
- Heavy Water (D_2O)
- Light Water (H_2O)

The neutron slowing down mechanism in this selection of reflectors varies from essentially all inelastic scattering (PbF_2), to purely elastic scattering (D_2O and H_2O). Beryllium fluoride uses a mixture of both inelastic and elastic scattering for neutron slowing down. The inelastic scattering cross section for fluroine is shown on Figure 1. The inelastic scattering cross section for lead has a value of approximately 2.0 barns from 3 MeV to 10 MeV. Thus, the inelastic scattering cross section for PbF_2 is significant over an energy range from 0.1 MeV to 10.0 MeV. Neutron slowing down due to elastic scattering with PbF_2 is not very efficient, and is not expected to contribute much to the slowing down spectrum. Light water is the most efficient at slowing neutrons down by elastic scattering of the reflectors being considered.

Results of the anaylses are shown in Table 1. From these results the following conclusions can be drawn:

- The shortest proton pulses result in neutron pulses in the moderators with the largest amplitudes for the H_2O moderator, regardless of reflector

- In the case of the liquid hydrogen moderator there is an optimum proton pulse length longer than the shortest one considered at which the neutron pulse amplitude is a maximum

- Lead fluoride reflector/pre-moderator results in the largest neutron pulse amplitude, for both moderators considered

The neutron pulse widths at half maximum for the light water moderator are shown on Table 2. These results show that the PbF_2 reflector results in a neutron pulse width which is approximatley 75% as narrow as those for the D_2O reflector/pre-moderator. The fractional difference between the pulses corresponding to a PbF_2 reflector and a D_2O reflector for the light water moderator are shown on Figure 2. The fractional change is positive up to 1.0(-4) s, and then becomes negative, approaching -1.0. This result shows that the pulse corresponding to the PbF_2 reflector rises faster than that corresponding to the D_2O reflector. In addition, the result indicates that the pulse corresponding to the PbF_2 moderator dies away faster than the one corresponding to the D_2O reflector. Finally, a study was carried out of the effect of poisoning (^{10}B) the moderator, on the neutron pulse width and the corresponding pulse amplitude. These results are shown on Table 2 and Figure 3.

Table 2 shows the variation in the width, amplitude, and time of the peak with the increased addition of ^{10}B. The amount of ^{10}B added to the light water moderator is measured in units of water absorption. Thus, enough ^{10}B is added to the moderator to equal ten times and fifty times the original absorption cross section of light water. It is seen that the pulse width can be reduced from 8.0(-5) s to 1.0(-5) s. However, the pulse amplitude is reduced by approximately a factor of five at the same time.

The neutron energy spectrum in the target (tungsten), reflector (lead fluoride), and moderators are also considered. It is seen that in the tungsten target the neutron energy spectrum peaks at approximately .44 MeV with a tail extending to 20.0 Mev. The spectrum in the reflector peaks at .022 Mev - .066 MeV with a lesser peak at 1.2 MeV. However, its fairly tight structure in energy is the result of the inelastic slowing down mechanism characteristic of this reflector. In the light water moderator there is a broad peak at approximately 0.057 eV. Finally, in the liquid hydrogen moderator there is a pronounced peak at 0.009 eV.

Finally, the time of the maximum amplitude in the various components was determined for two proton pulses (1.2(-6) s and 1.0(-3) s)). It was seen that for the short pulse the pulse in the heavy metal target and the reflector are clearly separated from the pulses in the moderators. In the case of the long proton pulse the neutron pulses in the heavy metal target and light water moderator essentially overlap.

4. Conclusions

The following conclusions can be drawn from this comparative study of proton pulse lengths and their effects on the neutron pulses:

- The result of using a short proton pulse length (~ 1.0(-6) s) are:
  - Moderator neutron pulses with larger amplitudes
  - Neutron pulses which have a narrower width at half maximum; and which rise faster, and die away faster,
  - Neutron pulses in the heavy metal target and reflector which do not overlap the neutron pulse in the moderator.

- The use of longer proton pulses (~ 1.0(-3) s) are:
  - Removal of the thermal-mechanical shock enhanced stresses in the target components,
  - Potentially more reliable operation and the possibility of a larger number of target design options.

5. References

[1] Powell, J.R., et al."The BNL 5 MW Pulsed Spallation Neutron Source", This Conference.

[2] Blumberg, L.N., "Preliminary Report on the BNL Spallation Neutron Source Design Study", 12th International Collaboration on Advanced Neutron Sources - ICANS XII, Abingdon, Oxfordshire, U.K. (May 1993).

[3] Katscher, W., Nuclear Technology, Vol. 35, p.557, (1977).

TABLE 1. NEUTRON PULSE HEIGHT

(Relative Unites) / P

LEAD FLUORIDE REFLECTOR

	MODERATOR	
Proton Pulse (s)	H_2O (0.0253 eV)	LH_2 (0.00405 eV)
1.2 (-6)	3.5	0.59
5.0 (-5)	2.9	0.62
5.0 (-4)	0.96	0.29
1.0 (-3)	0.53	0.18

BERYLLIUM FLUORIDE REFLECTOR

	MODERATOR	
Proton Pulse (s)	H_2O (0.0253 eV)	LH_2 (0.00405 eV)
1.2 (-6)	2.4	0.56
5.0 (-5)	2.2	0.56
1.0 (-3)	0.43	0.18

HEAVY WATER REFLECTOR

	MODERATOR	
Proton Pulse (s)	H_2O (0.0253 eV)	LH_2 (0.00405 eV)
1.2 (-6)	1.6	0.48
5.0 (-5)	1.5	0.49
1.0 (-3)	0.38	0.25

* 1.2 (-6) = 1.2 x 10^{-6}

TABLE 2. NEUTRON PULSE WIDTH AT HALF MAXIMUM

(s)

LIGHT WATER MODERATOR

	REFLECTOR	
Proton Pulse Width	Lead Fluoride	Heavy Water
1.2 (-6)	8.0 (-5)	1.3 (-4)
1.0 (-3)	6.2 (-4)	8.0 (-4)

EFFECT OF POISON ON MODERATOR PERFORMANCE

LEAD FLUORIDE REFLECTOR

LIGHT WATER MODERATOR

Poison Concentration (In multiples of H_2O abs.)	Width (s)	Relative Amplitude	Time of Peak (s)
1.0	8.0 (-5)	3.5	1.9 (-5)
10.0	2.5 (-5)	2.3	1.3 (-5)
50.0	1.0 (-5)	0.8	7.6 (-6)

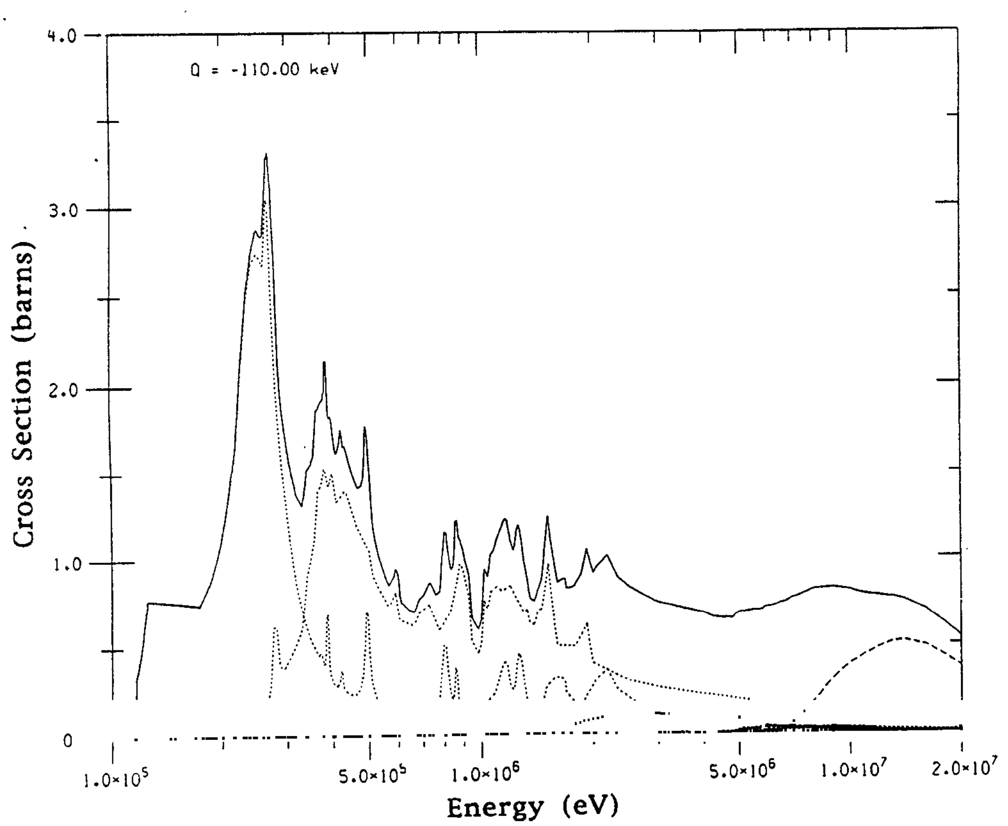

Figure 1 - Inelastic Scattering Cross Section for Fluorine

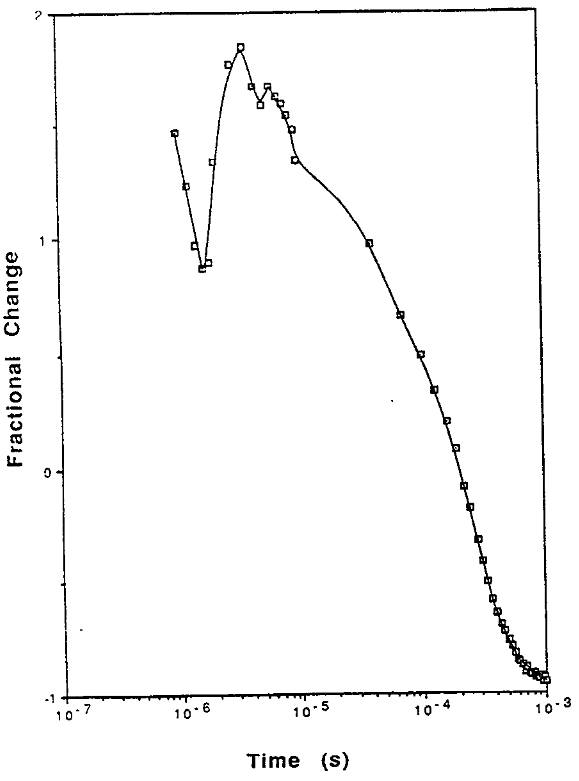

Figure 2 - Fractional Change in Pulse Amplitude

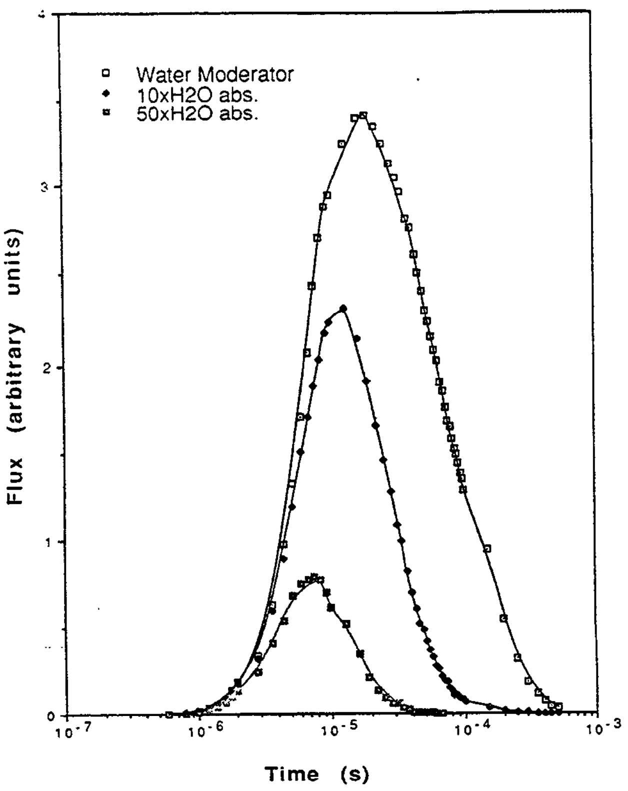

Figure 3 - Neutron Pulse in Light Water Moderator