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# Accelerator-Driven Targets: Understanding and Analyzing the Spallation Process

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## Introduction

Recent advances in accelerator technology have led to the practical realization of high-power beams. When coupled with high-power spallation target technology, these systems offer a more environmentally-friendly method of producing neutrons than reactors. We will focus our attention here on the application of spallation technology to the Accelerator Production of Tritium (APT).

*What is spallation, anyway? - Spallation* refers to nuclear reactions that occur when energetic subatomic particles (such as protons in an accelerator beam) interact with an atomic nucleus.[1] For the APT application, we are looking at a composite tungsten/lead target, and therefore, the nuclei of tungsten and lead atoms. Spallation takes place in two stages. In the first stage where the proton interacts with the target, the incident particle creates a high-energy cascade inside the nucleus. High-energy (>20 MeV) "secondary" particles and low-energy (<20 MeV) "cascade" particles escape the nucleus, leaving the nucleus in a highly-excited state. In the second or evaporation phase, the excited nucleus relaxes, primarily by emitting low-energy "evaporation" neutrons. For heavier nuclei (such as lead), high-energy fission can also occur, competing with evaporation. For lead, the dominant mode of nuclear deexcitation is by evaporation rather than high-energy fission. Tungsten can also undergo high-energy fission, but to a lessor extent than lead.

## Spallation Target Technology

*Spallation Target Design* - Maximizing the total low-energy neutron production is an important aspect of spallation target design—however, it is only part of the story. Once low-energy neutrons are produced inside the target, they must "leak" from the target before they can be used. Maximizing leakage and minimizing parasitic neutron absorption in the target are other crucial aspects of spallation target design. The main factors controlling neutron leakage are parasitic absorption in the target material and target geometry. Figure 1 shows various figures of merit (neutron production, leakage, and absorption) for solid cylinders of lead and tungsten. Notice that at large target diameters, the lead target leaks more neutrons than the tungsten target, but tungsten is a better neutron producer. For tungsten (and any other neutron absorber), the detrimental parasitic absorption effect is improved by splitting the target.[1-2] The use of a split target also helps mitigate excessive neutron leakage from the front surface of the target, which is desirable since these neutrons head back down the beamline and are lost.

*Neutronic Performance* - Target neutronic performance is a function of the energy and type of the incident particle as well as target material and geometry. Proton for proton, production of neutrons from a thick, heavy-metal target increases with beam energy. The low-energy neutron production rate per unit beam power, however, saturates at about 1.5 GeV.[3] Thus, factors other than the neutronic production rate drive a decision to go above this beam energy (e.g., the accelerator design). Engineering realities such as proton beam windows, target canister material, target dilution by cooling material, and the profile and size of the incident particle beam also affect the neutronic performance and design of a target. These practical matters must be explicitly dealt with in a realistic situation. Also, the neutronic interaction of a target with its immediate environment affects the overall performance of a spallation target system.

## Tritium Production - APT $^3$He Target/Blanket Concept

One example of an accelerator-driven target system is the APT $^3$He target/blanket concept.[4] The neutronic performance of the APT target/blanket assembly is calculated with the LAHET Code System.[5] The input model for physics calculations contains the essential features of geometry and materials. The APT $^3$He concept takes advantage of the large thermal cross section (~5300 barns) for the reaction

$$^3\mathrm{He} + n \rightarrow p + \mathrm{T}$$

to convert $^3$He to tritium. Alternatively, $^6$Li could readily be used as the feed material with nearly equal neutronic efficiency as that of the $^3$He system.

As noted in Fig. 1, low-energy neutron production from a spallation reaction increases with target diameter. One way to achieve "infinite" target neutron production for a "practical" spallation target with cooling (which enhances parasitic absorption in the target material) is to introduce $^3$He into the target to compete with parasitic absorption in the target at large target sizes as illustrated in Fig. 2.

Figure 3 illustrates the various components of the APT target/blanket design. The proton beam strikes the tungsten target elements in the central target region (the tungsten source array), producing neutrons through the spallation process. The backstop lead region ranges out the primary protons and catches any small-angle scattered protons from the central target region, producing spallation neutrons. The lateral high- and low-power lead zones are integral parts of the $^3$He target system; high-energy protons and neutrons escaping the central target zone can strike the lead and produce additional spallation neutrons. The $^3$He layer between the tungsten central target zone and the lead region, called the decoupler, neutronically decouples the central tungsten region from the lead target/blanket zone and produces tritium. Tritium is also produced in $^3$He contained in the lead regions. The $^3$He target/blanket system is an efficient way to make tritium utilizing an accelerator and the spallation process.

## References

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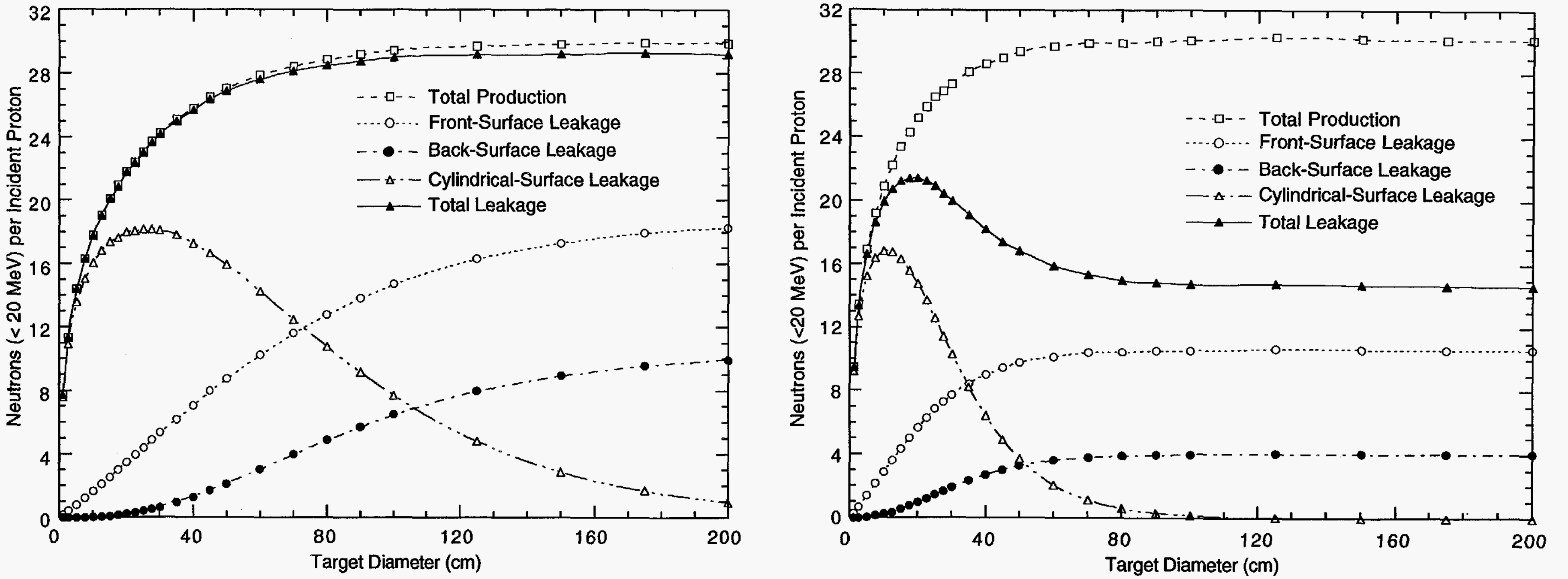

Fig. 1. Low-energy neutron production and leakage as a function of target diameter for solid cylindrical lead (left figure) and tungsten (right figure) targets bombarded on axis by a pencil beam of 1-GeV protons. The targets are stopping-length targets (55 cm for the lead target and 30 cm for the tungsten target).

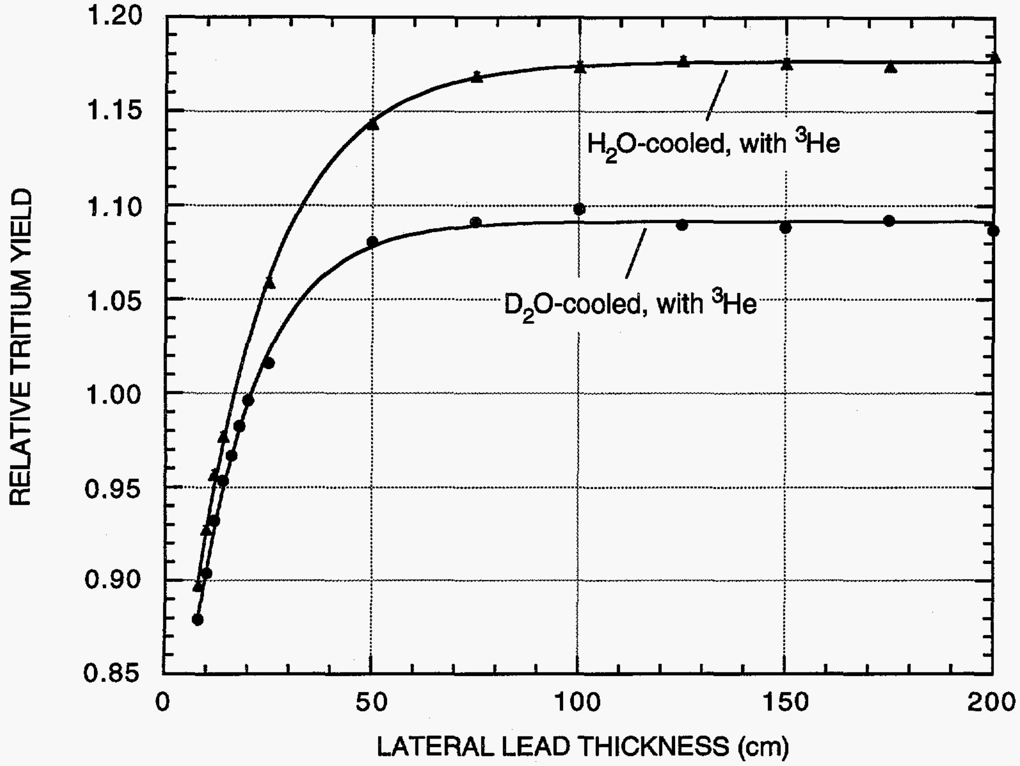

Fig. 2. Effect of $H_2O$ vs. $D_2O$ cooling of the lead target zone with $^3$He for a homogeneous mixture of lead $^3$He and coolant. The presence of $^3$He opens the possibility of approaching “infinite-target” neutron production. For a homogeneous system, $H_2O$ is a more effective coolant than $D_2O$ for the lead target zone.

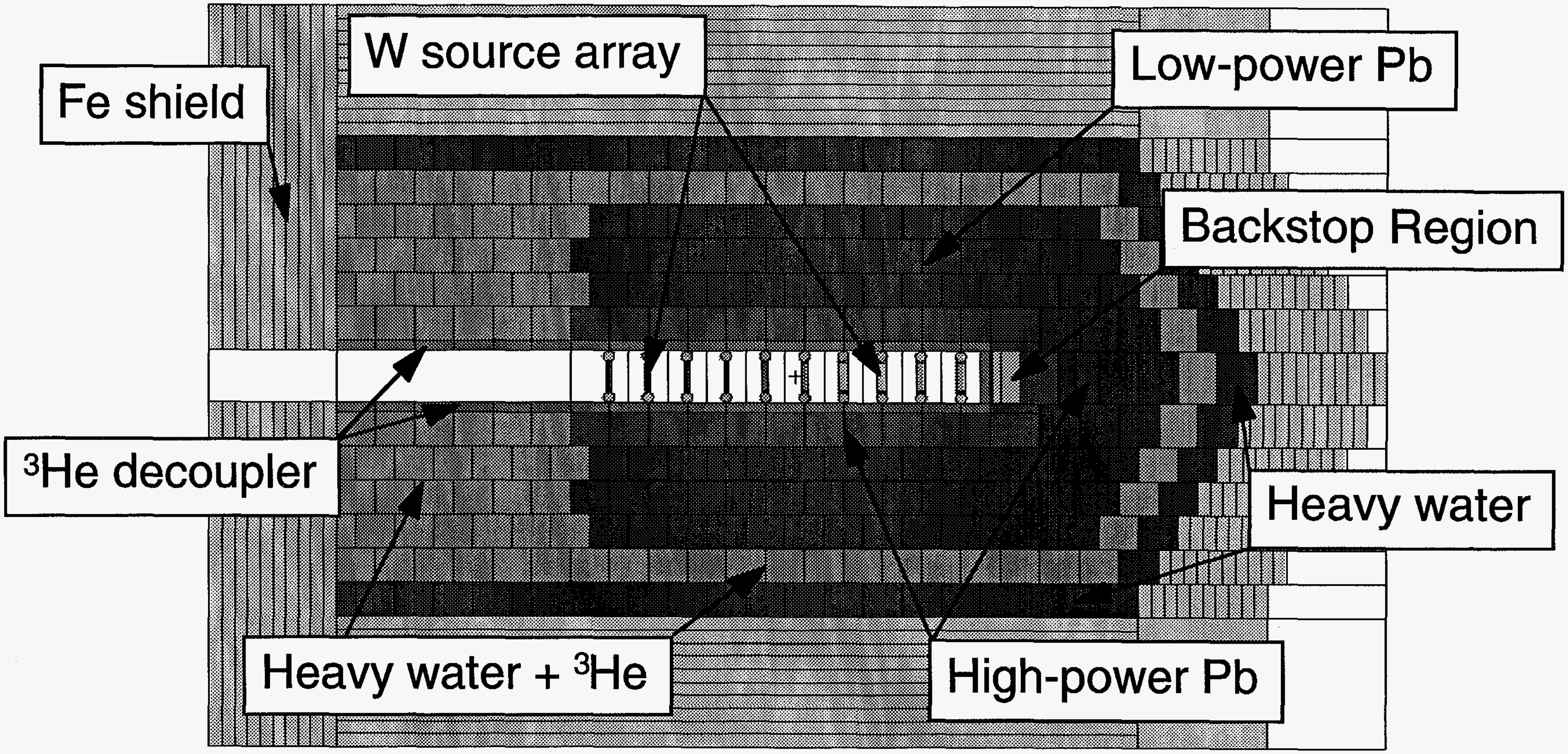

Fig. 3. Schematic of the APT target/blanket system.