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The supershield project evaluated the importance of novel shield configurations for suppressing neutron induced background in new classes of gamma-ray detectors such as CZT. The basic concept was to use a 2 part shield. The outer shield material heavily moderates the incoming neutron spectrum. This moderated neutron beam is then more easily absorbed by the inner material, which is an efficient neutron absorber. This approach is, in principle, more efficient than that in previous attempts to make neutron shields. These previous attempts involved biatomic, monlithic shields (eg. LiH) in which the shield consisted of a single material but with two types of atoms – one for moderating and one for absorbing. The problem with this type of monolithic shield is that moderating neutrons, without the efficient absorption of them, leads to the leakage into the detector of neutrons with a low energy component (~10-100 KeV). These energy neutrons are particularly problematic for many types of detectors.

The project was roughly divided into phases. In the first phase we attempted to carefully define the neutron source function incident on any space instrument. This is essential since the design of any shield depends on the shape of the incident neutron spectrum. We found that approximations commonly used in gamma-ray astronomy for photon background is inadequate. In particular there is a substantial error introduced by assuming that the mass of an instrument can be treated as an "equaivalent mass" of air, and then using the neutron production from that amount of air under comparable cosmic-ray exposure. This approximation is a routine one for gamma-ray background. The difficulty with this approximation is that neutron propagation and moderation is very sensitive to the atomic number of the material. In addition, we found that secondary neutrons produced in any passive shield, and dominated by inelastic neutron scattering, are far more important than background due to neutron activation. In order to properly account for this secondary neutron production we developed a procedure that scales the neutrons produced by primary and secondary cascades, and by neutron evaporation, according to the atomic weight of the material. We also had to derive the spectral shapes of the various neutron background components. For evaporative neutrons we developed a statistical gas model of the nucleus. This model explicitly accounts for the decrease in temperature of an excited nucleus as it emits protons and neutrons. Therefore it is much improved over the standard "evaporative" model characterized by a singe temperature, but is a superposition of many different temperature spectra. Other components such as cascade neutrons at higher energies (>20 MeV) were also carefully treated. The evaporative treatment was most important though, because as pointed out by us and others, these are the neutrons which are most damaging when partially moderated down in energy and subsequently interacting with a detector. The details of this work were presented in Harrison et. al. 2000.

The second phase of our work involved design of supershield geometries (one and three dimensional) in order to compare different shield configurations and materials for their effectiveness as neutron shields. Moreover we wanted to compare these supershields with previous neutron shields to confirm the performance differences between the supershield (two material) and monolithic (one material) designs and to understand the physics origins of these differences more clearly. In our early work we concentrated on NaI detectors because previous work on neutron shields had been done for the NaI. We were able to show using a three-dimensional radiation transport code that there was a substantial improvement afforded by the supershield geometries over the standard neutron shield geometries. We were able to explicitly confirm that the poor performance previously reported for neutron shields was indeed due to partial moderation in the shield. The neutron shields were moderating evaporative neutrons (energies ~ few MeV) down to energies of ~ 100 KeV, where the neutrons could lead to substantial resonant excitation of the NaI with resultant production of background gamma-rays through inelastic scattering. In this work we also tried a variety of different supershield materials which could be employed in space-based systems to determine the relative merits of various designs (Hong et. al. 1997,1998). A notable feature of this work was the substantial improvement which could be offered by the use of 3He as the neutron absorber in supershield systems. Another important feature was the recognition that bimolecular materials were superior to unimolecular materials as the moderating element. The reason is quite simple. Materials such as LiH or hydrated borate materials are not only efficient moderators but can absorb neutrons which have been partially modified "upstream" in the moderator section of the supershield.

The third phase of the supershield program involved the benchmarking of the supershield designs through direct experimental verification. This required fabricating various supershields and exposing them to beams of neutron to directly characterize their performance. The experiments concentrated on 10Boron based absorber materials and various hydrated organics (such as paraffin) for the moderator section. A unique neutron facility operated by medical physics groups at Columbia University was used. The facility is capable of generating highly monochromatized beams of neutrons generated in proton-tritium target interactions. The angle at which neutrons are emitted in this interaction is a strong function of neutron energy. Consequently monochromatic beams could be generated in the range from 100s of KeV to many MeV – the range of neutron energies most astrophysically important. These experiments demonstrated excellent agreement with theoretical predictions of supershield performance. This agreement is not just for overall numbers of neutrons penetrating the shield. The actual "leakthrough' spectrum of neutrons was predicated with high accuracy. These experiments explicitly demonstrate the utility of supershields as suppressions of neutrons of a factor of 2 or more could be obtained with basic supershields.

With explicit verification that our modeling procedures can be used with confidence, we are now in a position to design shields for realistic space geometries. The code suite that will be utilized, and that was assembled as part of this research, involves the use of a particle production code (GEANT) which is coupled to the radiation-transport code COG. This provides full 3-dimensional simulation capability. For less computationally internsive work we have ascertained that our own explicit construction of source functions for materials, as obtained by our modification of the equivalent air mass method, is as accurate as the particle production codes, especially given their uncertainties at the lower neutron energies (<~ 10 MeV) which are of most importance to the astrophysical background problem.

Using the supershield modeling capability developed as part of this program we are attempting to evaluate their utility for a specific proposed mission – the Energetic X-ray Imaging Survey Telescope (EXIST). It is anticipated that this experiment, which is limited by internal background at high energies, might benefit from a neutron shield. As a conclusion of this work, it is now understood that neutrons are most problematic at the lowest part of the gamma-ray energy band (<~ 20 KeV) and at the very highest energies (>~ 400 KeV). EXIST has an energy band from ~5-600 KeV, so it will serve as a promising testbed to evaulate the utility of neutron shields.

There are several other spinoffs of the supershield work that we think are of general interest. The first is in the area of design of optimal neutron shields for medical applications. Many medical facilities utilize proton beams as primary or secondary beam in the treatment of patients and shielding from neutrons is an important issue. We will pursue this avenue of inquiry as a spinoff of the supershield research since there are potential, as yet unevaluated, commercial implications. The other area is in direct detection of dark matter. The primary source of background in underground experiments to detect dark matter is neutrons produced in (alpha,n) reactions from decay of radioactive elements in rocks and tertiary neutrons produced in muon collisions (the driving reason to move dark matter detectors deep underground). It has been recognized for a number of years that neutron shields could have a significant impact on this issue. The suite of modeling tools we have developed will allow us to specifically address the optimization of supershields for the dark matter problem.

The following published papers describe in more detail the supershield effort. Reference 0 provides background information on the concept and was written prior to the commencement of the work. All the other papers were a direct result of the funding obtained in the supershield research effort.

C.J. Hailey and F.A. Harrison, "A New Concept in Background Rejection for Gamma-ray Astronomy: The Supershield," Nucl. Instr. Meth. A., 265, 518, 1995

J. Hong and C.J. Hailey, "Modeling and Suppression of Neutron Background in Gamma-ray Detectors," SPIE vol. 2806, p.449, Gamma-ray and Cosmic-ray Detectors, Techniques and Missions, B. Ramsey and T. Parnell Eds., 1997.

J. Hong, C.J. Hailey and W.W. Craig, "Development of Neutron Shields for Gamma-ray Detectors," SPIE vol. 3445, p.121, EUV, X-ray and Gamma-ray Instrumentation for Astronomy IX, O. Siegmund and M. Gummin Eds., 1998.

J. Hong, C.J. Hailey and W.W. Craig, "Laboratory Tests of Neutron Shields for Gamma-ray Detectors in Space," Nucl. Instr. Meth., submitted 2000.

F. Harrison, C.J. Hailey, J. Hong, A.S. Wong and W.R. Cook, "Background in Balloon-borne Hard X-ray/Soft Gamma-ray Cadmium Zinc Telluride Detectors," Nucl. Instr. Meth., accepted 2000.