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The SNAP Shielding Program at ORNL*

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The SNAP shielding program at Oak Ridge National Laboratory is only one phase of a program of theoretical analysis, calculation, and experimentation related to the radiation shielding problem. Obviously, the requirements of the program have become more stringent and exacting as nuclear energy has been applied to mobile systems. As part of the departed but not forgotten ANP program, the Tower Shielding Facility was constructed at Oak Ridge to make possible in-air large-scale experiments in support of the shielding program. Despite the demise of the ANP program, a great deal of valuable technology, including shielding data, was generated. The Tower Shielding Facility has since then been used in checking calculations for vehicle shielding and in establishing the shielding effectiveness of various structures, and will in the near future be used to check the shielding of a SNAP-2/10A reactor. The aims of the program remain the development of advanced techniques for accurate calculation of the dose delivered through and around a shield to any point on a given dose plane, and permit optimization of shield shape and weight.

The Tower Shielding Facility at ORNL is shown in slide 1 (Photo 53816). Control room and counting rooms are shielded by concrete and earth fill. The towers are about 300 feet high and can elevate a load of 55 tons in the plane of the two nearer towers to a height of about 125 feet. The reactor shown here and in the next slide (Photo 55847) is the second reactor to be used here and, as the first reactor, has a water-moderated and cooled core. The third slide (Photo 50366-C) shows the flexibility of experimental arrangements achievable with this

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installation. The reactor is now enclosed in a collimator so that a beam of radiation may be directed over a range of directions. The nearer sphere is a 10-ft detector collimator that, when filled with lead and water, attenuates neutron dose by a factor of 10^4 and gamma dose a factor of 10^6 thus permitting discrimination of spacial distribution of incoming radiation. This facility then we plan to use for some work with a SNAP reactor, which will be described later.

A natural question in connection with shielding research is "Why is it necessary?" After all, shields have been designed and built for many years now with considerable success. Back in 1957 a shielded reactor was flown in an airplane and measured neutron dose rates were found to be within a factor of 10 of calculated predictions in most cases. The simplest answer, of course, is that factors of 10 are not good enough in space applications. However, in addition there is the problem of uncertainty, for some calculations, especially when departure is made from the simplest geometries, often differ widely from measurements. The dose rate at any given point within a shielded volume consists of several components each of which is contributed by a distinct set of physical processes. These component parts of the total dose rate can vary sharply with change of geometry, materials, and radiation source. As a matter of fact, knowledge of the physical processes themselves is constantly being supplemented; that is, interaction cross sections are still under investigation.

In the SNAP systems that have been seriously proposed, the principal concern, so far as shielding is concerned, has been the protection of instruments from radiation damage. The damage threshold in instrument payloads is invariably reached earlier in the course of accumulation of neutron dose than of gamma-ray dose. For this reason, most attention has been focused on the neutron component of radiation emanating from the reactor core.

The best shielding material for neutrons in space systems is lithium hydride. It is relatively light, having a fabrication density of 0.74 to 0.77 at room temperature and a macroscopic cross section of about 0.15 per cm when the thicknesses considered are not over 2 ft. A few years ago the value of the various microscopic cross sections that make up the average value of macroscopic cross sections were very much in doubt. Some cross sections had just been declassified, and to verify calculations in which geometry played a minimum role, some experiments on the transmission of neutrons through slabs of lithium hydride were conducted at the Tower Shielding Facility. The 12-ft diameter spherical collimator was used to obtain beams of neutrons 6 in. in diameter and 15 in. in diameter that were directed through slabs of lithium hydride of various thicknesses. Calculations were done using the Monte Carlo technique as incorporated in the OSR code developed at Oak Ridge. The results are shown in the next slide and were interpreted as confirming the relative accuracy of cross sections and the adequacy of the number of histories selected for calculation.

This was one of the first tests of the Monte Carlo method code known as MC at Oak Ridge National Laboratory. Monte Carlo is the most accurate method presently available for calculation of radiation transmission through material, and it is the only method that is not limited by geometry of the source-shield combination. However, there are still problems in using this method in that good accuracy of dose prediction requires a sufficient number of histories to be run with useful biasing techniques along with an evaluation of the statistical error inherent in the calculation (at least 5,000). Also consistent errors in programming are not difficult to make and very difficult to discover, once made. The problem of transmission through the slabs, for example, required many hours of machine time on a CDC-1604 computer to evaluate biasing techniques and to reduce the statistical deviation for 25,000 neutron histories.

There are, of course, other less meticulous methods of calculation. The next slide lists some of them. The dose predictions for the SNAPSHOT experiments -- the orbited SNAP-10A reactor of Atomics International -- were made by the point-kernel method as developed by Goldstein at United Nuclear Corp. However, the dose at the payload plane was not dominated by the neutrons that penetrated the shield but by the neutrons scattered around the shield by structural components of the system. Even so, the predictions obtained were quite good for a small unmanned system, varying from 10% below the measured dose to 300% above. In the past, calculations of dose rates for the ANP program using kernel methods yielded results that were from 50% too high to a factor of 2.7 too low.

The scattering of neutrons by structure was illustrated at ORNL in a series of experiments utilizing the TSR-II reactor. The next slide shows the scheme of the experiments (ORNL 2-01-056-35-1300). The truncated cone below the TSR-II core is a water tank, representing a SNAP system shield. A beryllium block, simulating a SNAP reactor control drum is mounted adjacent to the reactor core as shown in the next slide (Photo 58047). In addition to the beryllium, a small cylinder of nickel was mounted above. The beryllium could be swung away from the reactor vessel so as to come out farther from the shield shadow cone, as shown in the next slide (ORNL 2-01-056-35-1381).

The detector collimator traversed horizontally from the center line of the shield to about 8 in. to the right of the edge of the shield. In other words, it moved from the shadow of the shield out to where it looked directly at the beryllium. In the next slide are some of the results (ORNL 2-01-056-35-1383). Positions 0, 1, 2, 3, are positions of the beryllium progressively farther out from the reactor vessel. The rise in dose rate clearly indicated that the directions of neutrons are changed in collision with beryllium atoms and increase the

dose received even well within the shadow of the shield. The next slide (ORNL 2-01-056-35-1384) shows the same results but with tighter collimation, 3-in. collimator as compared to an 8-in. collimator in the previous results. The total dose rate per watt of reactor power is down as would be expected, but the change in dose rate with beryllium position is greater. The next slide shows (ORNL 2-01-056-35-1385) the increments of dose for each position of the beryllium blocks. The background has been subtracted so that these dose rates represent increments due to scattering only. The effect of the very small, 1-in. diameter by 1-in. high nickel cylinder is clearly visible above background. These experiments gave an indication of the total effect to be expected from structural scattering and in the SNAPSHOT flight the scattering effect was the dominant dose contributor over most of the dose plane.

Over the next couple of years the program at ORNL is oriented toward development of advanced mathematical techniques for calculating accurately neutron transport through shields and for calculating by iterative processes a minimum weight design for a given mission profile. The program includes improving the O5R code, including amplification of the cross-section library and coupling of this code with the Sn code to achieve shorter machine time for a larger number of neutron histories. The program also envisages development of a two-dimensional Sn-Pn code and coupling of O5R and OGRE codes and Sn-OGRE for rapid calculation of secondary gamma-ray generation and the resultant dose contribution.

First problems to be undertaken by these mathematical programs will be related to a SNAP 2/10A system and to provide experimental verification of the calculations. A SNAP reactor will be installed at the Tower Shielding Facility. The experimental program will be divided into three major parts. First will be mapping of the leakage flux from the core as shown in the next slide (ORNL Dwg. 65-7228).

The reactor will be suspended on a lead screw at the end of a boom fixed to a rotatable column. In the position shown here, with the reactor at not over one watt power, a collimator for a neutron spectrometer will rotate about the core while maintaining its focus on one point in the reactor. This procedure will yield a source spectrum for use in subsequent calculations.

The second part of the program is represented by the next slide (ORNL Dwg. 65-7229). Here the dose and spectrum transmitted through a lithium hydride shield will be mapped. The detector collimator will be placed in a dry chamber that will be shielded from air-scattered and structure-scattered radiation by concrete cover slabs. The shield itself will be surrounded by a polyethylene and iron collar to exclude air-scattered neutrons. The design of this collar and the validity of this experimental configuration is at present the subject of both theoretical and experimental study. Calculations indicate that the collar will be effective in preventing distortion of shield performance in space by the earth-bound environment. However, an experiment utilizing the TSR-II will be conducted shortly to verify this. The configuration is shown in the next slide.

The third phase of the program will be concerned with structural scattering contributions as shown in the next slide (ORNL Dwg. 65-7231). A view of the overall facility for the reactor installation is shown in the next slide (ORNL Dwg. 65-7616). It is hoped that the installation will be flexible enough to allow some extension of the program into thicker shields and eventually to allow verification of shield shaping calculations that may in the future contribute to weight saving in manned as well as unmanned space systems.