The Monte Carlo Method: Versatility Unbounded In A Dynamic Computing World
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MCNPX VS. DORT FOR SNS SHIELDING DESIGN STUDIES

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ABSTRACT

A comparison of radiation transport through the 18-meter-long access way adjacent to the Spallation Neutron Source accelerator tunnel and 2.2-meter-thick massive shielding door which closes the access way was performed using both Monte Carlo (code MCNPX) and discrete ordinates (code DORT) methods. The beam losses during the accelerator operation are the sources for the radiation calculations. A variety of typical materials for accelerator shielding, such as concrete and steel, were used for the door to study radiation penetration. Analyses show that the results from the two methods are in good agreement.

Key Words: shielding, accelerator

1 INTRODUCTION:

The Spallation Neutron Source (SNS) [1] is powered by a high intensity, 2-mA, 1-GeV proton beam, which is accelerated in the linear accelerator and then accumulates in the ring to 1-μs-long pulses before being injecting into a mercury target. A radiation field appears in the SNS accelerator tunnel mostly due to secondary particles created from the interaction of the proton beam halo with components along the proton beam line. Out of necessity, there are a number of penetrations adjacent to the tunnel which must be safely shielded. So it is important to provide reliable radiation transport analyses for streaming through the penetrations and through the bulk materials.

A comparison of radiation transport through the 2.2-meter-thick massive shielding door, which closes the 18-meter-long truck access way adjacent to the SNS accelerator tunnel in the high-energy-beam-transport line (HEBT) section following the linear accelerator (linac), was performed using both Monte Carlo (code MCNPX [2]) and discrete ordinates (codes DORT[3] and ANISN [4]) methods. High density concrete, steel with different elemental compositions, and a combination of steel followed by a layer of regular concrete were considered as possible materials for the door. For academic interest, a pure iron door was also investigated. This problem was chosen for comparison because the secondary radiation field in the tunnel near the access way was considered to be typical for the accelerator tunnel.

2 METHODS:

The accelerator tunnel is a large and complex structure, and for analyzing local problems only a portion of the accelerator is modeled. A detailed MCNPX model of the HEBT section was developed (Fig. 1) for the analyses.

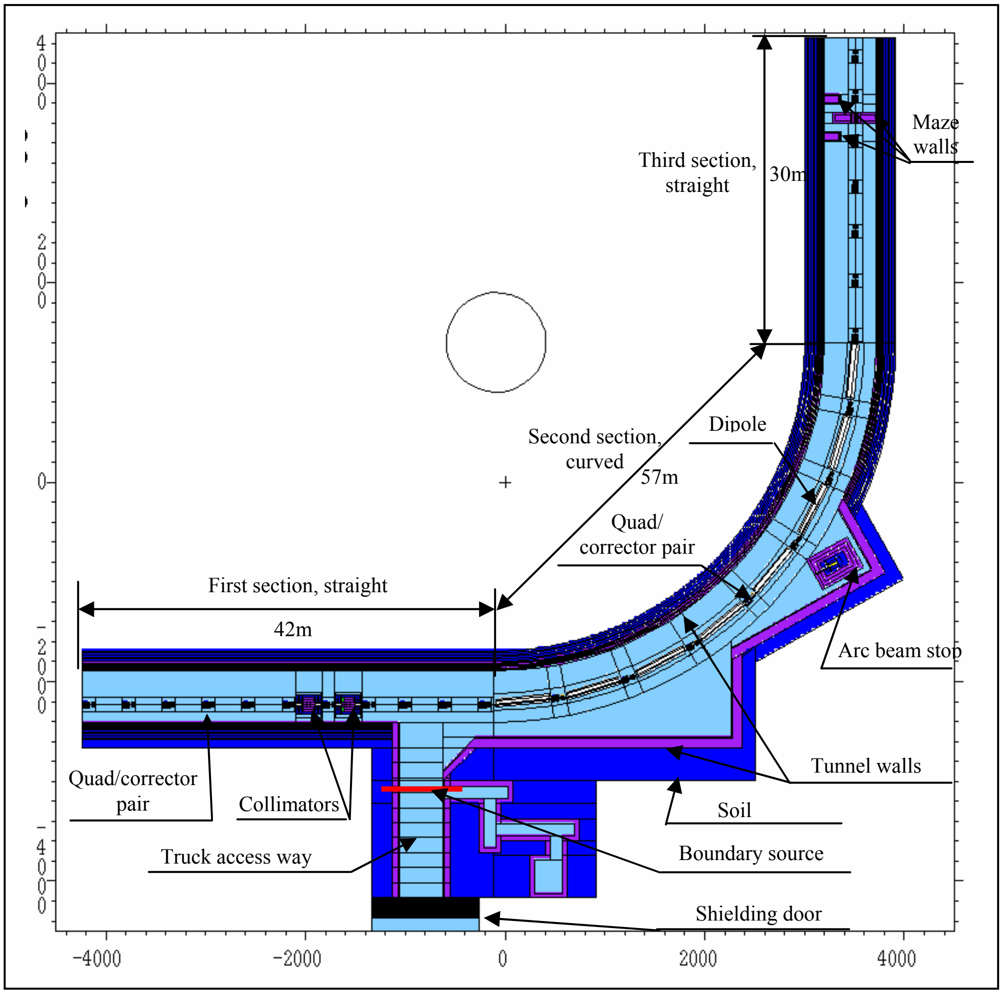

Figure 1.MCNPX model for HEBT

The neutron dose rate estimation outside the HEBT truck access way was performed in two steps. In the first step the MCNPX code was used to create a boundary source of secondary neutrons and photons at the beginning of the truck access way (red line in Fig. 1) originating from the anticipated operational beam losses in the particular accelerator section during normal operation. In the second step the radiation streaming through the access way and penetration through the massive door was simulated using both the Monte Carlo (MCNPX) code and the two- and one-dimensional discrete ordinates (DORT and ANISN) codes. In the second step the MCNPX simulation was performed using the real geometry, and reading as a source term the boundary source file created in the first step. Radiation transport through the 2.2-meter-thick shielding door was forced by geometry splitting. In the second step with the DORT simulation the rectangular access way, surrounding concrete walls, and shielding door were converted into an idealized cylindrical model conserving the absolute area of the tunnel and wall cross sections. The coupling code MTD [5] was applied to process a boundary source file for the two dimensional discrete ordinates transport code DORT from the file of boundary crossing events. A 100 directional downwards biased quadrature set was used. For the ANISIN simulation, additional MCNPX transport trough the access way was performed up to shielding door and a secondary boundary source file was saved. Then, using the coupling code MTA [5], this source was processed to the boundary source for the one dimensional discrete ordinate code ANISN. A simple slab model for the shielding door was created. A 64 directional spherical quadrature set was used. The coupled neutron/photon HILO2K [6] cross sections with P5 as the maximum order of scattering expansion were used for both DORT and ANISIN calculations.

High density concrete, steel with different element compositions, and a combination of steel followed by a layer of regular concrete were considered as possible materials for the 2.2-meter-thick shielding door in the studies. For academic interest, a pure iron door was investigated as well.

3 GEOMETRY MODEL:

The MCNPX HEBT model describes a portion (129 meters) of the about 170-m-long tunnel that starts downstream of the long linear accelerator and exits into the accumulator ring. 75-cm-thick concrete walls form the HEBT tunnel, which is 4.3 m wide and 4.5 m high. The beam centerline is 1.25 m above the floor and 1.75 m from the tunnel wall. Various accelerator components are placed in the HEBT, accumulator ring, and RTBT sections to collimate and correct the beam. Figure 2 shows the MCNPX model for the HEBT.

The first 42 m of the HEBT tunnel is a long straight section housing 6 pairs of quadruple magnets and correctors (referred to as quad/corrector pairs), followed by a collimator, another quad/corrector pair, a second collimator, and 4 more quad/corrector pairs. The 18-meter-long truck access way, which is 3.66 m high and 4.3 m long, is adjacent to the downstream end of the first straight section. The concrete walls are 78 cm thick (Fig. 1) and surrounded by soil. A 2.2-meter-thick massive shielding door closes the access way.

The second 57-m section is curved through an 81.3-degree arc, with a beam line radius-of-curvature of about 36 meters. This curved section houses 8 large dipoles with a quad/corrector pair between each dipole and an arc beam stop. Only the first 30-meters from the third section are modeled. The section is straight and filled with 7 pairs of quadruple magnets and correctors, and three transverse shield walls forming a maze.

The large dipole magnets have an overall length of 5.7 m and are comprised of two sets of large horizontal copper windings with iron cores – one above and one below the beam line. The dipoles have a thick steel support structure on the top and bottom, which runs almost the full length of the dipole, as well as a thick back shielding plate facing the inner wall of the tunnel; the fourth side facing the outside wall of the tunnel, is open. The quadruples each have 4 copper coils with individual iron cores, where the planes and the windings are normal to the beam, but where the coils themselves are physically rotated 45 degrees relative to the horizontal and vertical planes. The four coils are shielded and supported by a thick external iron structure measuring 63 cm square on the outside and 77 cm in length. The corrector units downstream from the quadruples are smaller still and are about 41 cm square by 35 cm long. The collimators are more complex, heavily shielded, 1.8-m-diameter units with an overall length of 2.6 meters. The beam enters a large-diameter hole in the 66-cm-thick upstream iron shield, and then passes through a thin platinum scraper. It enters a smaller diameter hole going through a 15-cm-long water-cooled section, and 1.2-meter-long particle bed, before emerging through the larger opening of the iron shield further downstream. The particle bed is 21.5 cm thick, with iron shielding extending beyond that to an outer radius of about 1 meter.

Each repeating HEBT tunnel component has been modeled separately and placed into the final model using the MCNPX repeated structure capability (transformation, universes and filling cards).

4 SOURCES:

The sources for the transport calculation in the first step are the beam (H^- or proton) losses at 1 GeV energy, and defined as a fraction of the beam interacting with the beam tube and components [7]. The losses are not uniformly distributed in the accelerator sections and the fraction of the beam lost depends on the location.

Both controlled and uncontrolled losses appear in the HEBT section. Uncontrolled losses are 1 Watt/m, which could appear everywhere and correspond to the $5 \bullet 10^{-7}$ beam fraction/m, assuming 2 MW accelerator operation. The controlled losses appeared in both HEBT collimators (a beam fraction of $5 \bullet 10^{-6}$ in each) and in the HEBT arc beam stop (a beam fraction of 10^{-3}).

For the Monte Carlo transport simulation in the first step the proton beam losses were described as a continuous set of cylindrical surface sources with a 2.6-cm radius located inside the beam tube, with uniformly distributed 1 GeV protons along each cylindrical surface. The direction of the protons, as the direction of axis of each cylinder, is parallel to the direction of the nominal proton beam. The source intensity in each cylindrical surface source corresponds to the integral beam losses in the specified component.

The second step used the boundary source, with neutron and photon crossing events in the beginning of the truck access way, created in the first step.

5 RESULTS:

The following materials were used for radiation transport study through the 2.2-m-thick truck access way shielding door:

- pure iron
- 1.9 m of pure iron followed by 0.3 m of regular concrete
- High carbon cast iron, 95% iron and 5% carbon (weight %), which is not actually a real material, just one composition for shielding study for iron plus light weight element composition
- Steel with 97% of iron and 1% each of magnesium, nickel and copper (weight %)
- SEG steel, junk steel in blocks, used for SNS shielding with averaged over 10 sampled blocks (Fe, 87.69%; Mn, 0.68%; Si, 0.52%; P, 0.03%; C, 0.324%; S 0.035%; Ni 3.9%; Mo, 0.26%; Cu, 0.87%; Co 0.009%; Nb 0.03%; Al, 0.465% and Cr 3.956%, weight %)
- 1.4-m of SEG steel followed by 0.8-m of regular concrete
- High density concrete (density 3.91 g/cm^3)

Figures 2 and 3 present the dose rate distributions through the 2.2-meter-thick shielding door built up from the materials listed above, calculated by MCNPX, and DORT respectively. The analyses show that the best shielding is high carbon cast iron (5% carbon). The SEG steel provides really good shielding especially combined with concrete behind it.

Figures 4-9 present comparisons for dose rate distributions for the above-listed materials calculated by MCNPX, DORT and ANISN. The comparison shows consistent results with both methods for all materials except for pure iron. In this case both DORT and ANISIN underestimate the dose rate by about a factor of three, even when improved iron cross sections from the HILO2k library are used. For thickness up to 1 meter the results are in a good agreement for all materials. Adding 0.3 m of concrete at the outside end of the door shielding brings the neutron dose rates behind the door into good agreement when calculated by both methods, even for the pure iron case. The inconsistency for the pure iron is more likely due to difficulty with description of iron window by group cross-sections. However, from the shielding design point-of-view, the results from both methods are in good agreement.

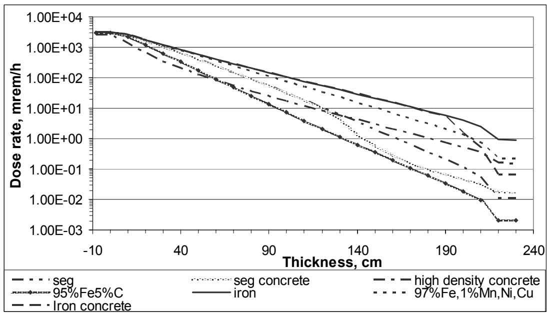

Figure 2. Dose rate distribution inside a shielding door made from different materials, calculated by Monte Carlo code MCNPX; mrem/h.

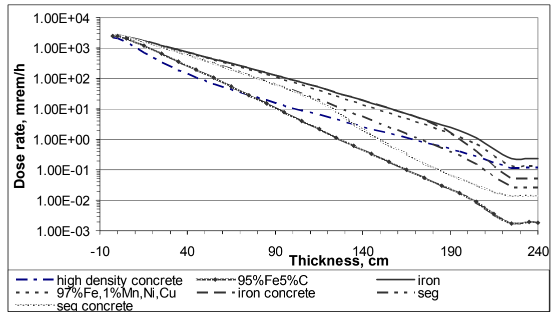

Figure 3. Dose rate distribution inside a shielding door made from different materials, calculated by discrete ordinates code DORT; mrem/h.

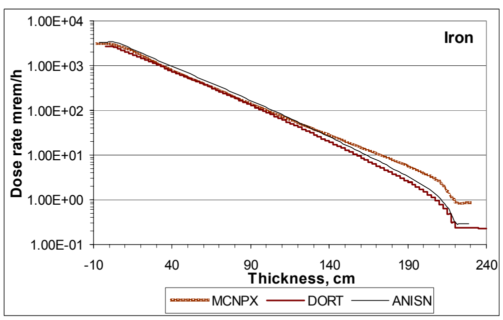

Figure 4. Dose rate distribution inside an iron shielding door, calculated by Monte Carlo code MCNPX and discrete ordinates code DORT; mrem/h.

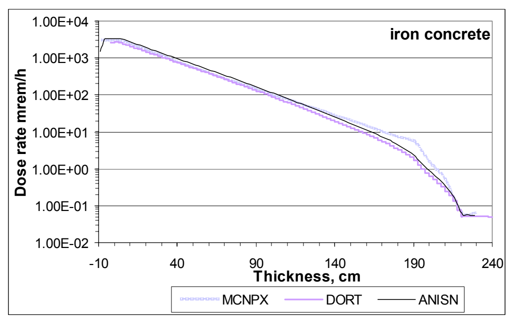

Figure 5. Dose rate distribution inside a shielding door of 1.9 m iron followed by 0.3 m concrete, calculated by Monte Carlo code MCNPX and discrete ordinates code DORT; mrem/h.

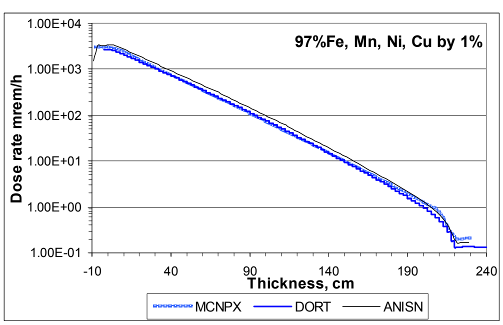

Figure 6. Dose rate distribution inside a steel shielding door, calculated by Monte Carlo code MCNPX and discrete ordinates code DORT; mrem/h.

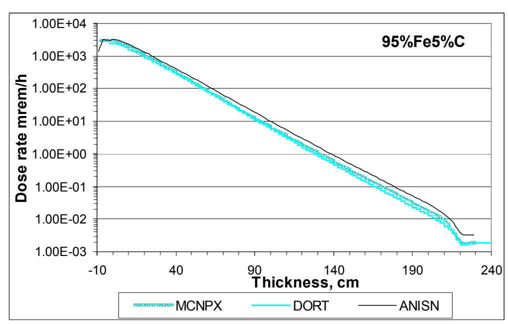

Figure 7. Dose rate distribution inside a cast-iron shielding door, calculated by Monte Carlo code MCNPX and discrete ordinates code DORT; mrem/h.

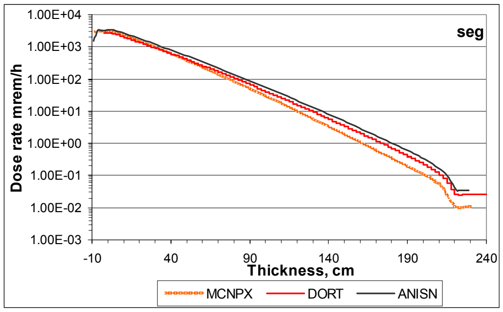

Figure 8. Dose rate distribution inside the SEG steel shielding door, calculated by Monte Carlo code MCNPX and discrete ordinates code DORT; mrem/h.

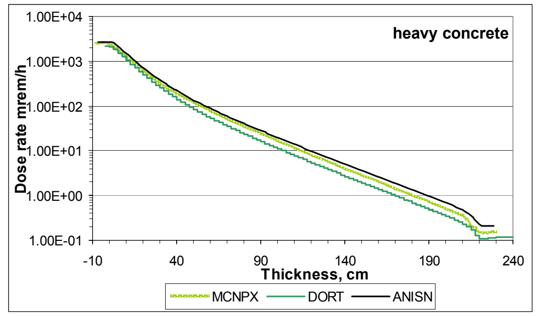

Figure 9. Dose rate distribution inside a high density concrete shielding door, calculated by Monte Carlo code MCNPX and discrete ordinates code DORT; mrem/h.

6 CONCLUSIONS:

A comparison of radiation transport through the 18-meter-long access way adjacent to the SNS accelerator tunnel and the 2.2-meter-thick massive shielding door made from different shielding materials and combinations was performed using both Monte Carlo (code MCNPX) and discrete ordinates (code DORT and ANISN) methods.

The comparison shows consistent results with both methods for all materials except for pure iron. In this case DORT and ANISN underestimate about a factor of three even when improved iron cross sections from the HILO2k library were used. Adding some amount (about 0.3 m) of concrete in the end of the shielding door makes the results from both methods consistent.

7 REFERENCES

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