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Shielding Calculations and Verifications for the New Radiation Instrument Calibration Facility at Los Alamos National Laboratory

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SUMMARY
MCNP-4C[1] was used to perform the shielding design for the new Central Health Physics Calibration Facility (CHPCF) at Los Alamos National Laboratory (LANL). The problem of shielding the facility was subdivided into three separate components: (1) Transmission; (2) Skyshine; and (3) Maze Streaming/ Transmission. When possible, actual measurements were taken to verify calculation results. The comparison of calculation versus measurement results shows excellent agreement for neutron calculations. For photon comparisons, calculations resulted in conservative estimates of the Effective Dose Equivalent (EDE) compared to measured results. This disagreement in the photon measurements versus calculations is most likely due to several conservative assumptions regarding shield density and composition. For example, reinforcing steel bars (Rebar) in the concrete shield walls were not included in the shield model.

I. BACKGROUND

The ESH-4 Radiation Instrumentation Calibration (RIC) Team at LANL received permission to build a new state of the art facility for calibration and evaluation of radiation instruments and dosimeters. The CHPCF, located at Technical Area-36 building 214 (TA-36-214), consists of a Neutron Free-In-Air (NFIA) room, Gamma Free-In-Air Room (GFIA), High and Low Gamma Beam Irradiator Rooms (GBI), and an x-ray room. The radioactive source inventory includes both photon sources (Cs-137) and neutron sources (Cf-252 and AmBe-241). The sources in the GBI rooms are housed in ISO type irradiators that provide a tightly collimated horizontal beam.

During the conceptual design phase of the project, it was decided that all the building and associated shield walls would be constructed of ordinary concrete for construction and cost considerations. The Los Alamos Monte Carlo code MCNP-4C[1] was used to perform the shielding analysis for this facility and to optimize the maze and shield requirements. The shielding was designed to meet two design-basis goals: (1) to maintain occupational and non-occupational doses As Low As Reasonable Achievable (ALARA) below the design basis; and (2) to limit the radiation cross-talk between rooms, thereby allowing simultaneous calibrations of instruments in adjacent rooms of the facility. The maximum design basis limit chosen for this facility was 0.25 mrem/h, which would result in an annual effective occupational dose of 0.5 Rem for continuous operations and occupancy. An additional design basis for the facility was to maintain the dose at 150 meters (nearest public access) below 20 mrem per year using a facility workload of 1000 hours per year and occupancy factor of 1/16. This paper discusses the methodology and variance reduction techniques used to determine the required shielding for the NFIA room, GFIA room and the High GBI room. The results from these calculations are then validated with measurements.

II. APPROACH

A. MCNP™ Calculations

The MCNP -4C[1] code was used to determine the fluence for both photon and neutron Effective Dose Equivalent (EDE) rate calculations. The neutron transport calculations include the effect of capture gamma production. An adequate number of histories were run in combination with variance reduction techniques such that most simulations passed MCNP's 10 statistical checks. For all cases, the relative error was less than 10% for the type F2/F4 tallies and 5% for type F5 tallies. However, some of the statistical criteria were relaxed for those calculations near background levels, and in these cases the true dose rates were believed to be within a factor of two of the reported mean.

At each tally location, the calculated fluence was converted to the EDE rate by scaling to the maximum source strength and folding in fluence-to-dose conversion factors. For neutron EDE rate calculations, fluence-to-dose conversion factors from 10 CFR 835.2 were used. For photon EDE rate calculations, fluence-to-dose conversion factors from ANSI/ANS-6.1.1-1991[2] were used.

The EDE rate was determined at the following locations within and outside TA-36-214 from calibration operations occurring in the NFIA room, GFIA room and High GBI room: (1) 25, 50, 100 and 150 meters east of TA-36-214 from the skyshine and transmission components through primary/secondary shield walls; (2) inside the facility from the transmission and skyshine components through primary and secondary shield walls; and (3) maze openings.

Once the initial shielding was determined to meet design objectives, these requirements were provided to the Architect/Engineer (AE) in charge of the project. The AE would then ensure all appropriate AE requirements were being met, e.g. seismic, mass loading, etc., and provide comments back to the shield designers. This iterative process continued until the final design was agreed upon.

B. Source Term

The source term for the NFIA, GFIA, and high GBI rooms used in all MCNP calculations was normalized on a per Curie (Ci) basis. Table 1 depicts the maximum source strengths to be used in the facility.

Table 1: TA-36-214 Source Inventory

	Isotope	Curie (Ci)
NFIA	Cf-252	0.108
GFIA	Cs-137	10
High GBI	Cs-137	1590

C. Shield Materials

The composition of the concrete shield was taken as ordinary concrete with an elemental atomic density given by ANSI/ANS-6.6.1-1987.[3] The concrete density used was 2.3 g/cc. Dry air was used for all skyshine calculations. The ground composition was also taken from ANSI/ANS-6.6.1-1987[3] with a density of 1.7 g/cc.

III. MCNP™ CALCULATIONS/METHODOLOGY

The MCNP™ calculations were done in three separate phases: (1) transmission, (2) skyshine, and (3) maze transmission/streaming. For the skyshine component, the ground plane was modeled as a horizontal plane, which is a simplification of the actual terrain surrounding building 214. For MCNP™ calculations involving the high GBI room, two MCNP™ runs were done for each phase. The first run did not include a scatter object in the beam of the ISO irradiator. The second run did include a scatter object to simulate an instrument being calibrated. The scatter object was modeled as a 34-cm diameter aluminum sphere, with a wall thickness of 2-cm, placed 50-cm away from the ISO irradiator.

A. Transmission Calculations

Type F2 and F5 tallies were both used to determine the EDE rate from the transmission component through primary and secondary shield walls. For both tally types, cells that would not contribute directly to the tally (e.g. floor, ceiling, secondary shield walls, etc. NOT adjacent to the tally location) were modeled as two Mean Free Paths (MFP) thick. After traveling two MFPs, particles were killed in these cells.

F2 tallies were used to determine the EDE rate on contact with primary shield walls. The walls were segmented so the EDE rate was determined in an area between two and six feet above the floor plane having a width of three feet. The walls were segmented in this manner to determine the EDE rate the whole body of an average person would be exposed to. Only the result for the wall segment having the highest EDE rate is reported. Geometry splitting/Russian roulette was used to maintain a fairly constant particle population with increasing depth into the shield wall. The importance function was allowed to increase between adjacent cells by no greater than a factor of four. If more than a factor of four was needed to maintain the particle population approximately equal in adjacent cells, the cell was split into smaller cells.

Type F5 tallies were used to determine the EDE rate in the center of adjacent rooms from the transmission component through the primary shield wall. A point detector was placed 150 cm above the floor plane. A PD card was used to ensure that only contributions from the transmission component through the primary shield wall were tallied. Contributions from the floor, ceiling and secondary shield walls were not allowed to contribute to the tally. These contributions were determined in subsequent calculations (e.g. skyshine calculations).

B. Skyshine Calculations
Type F5 tallies were used to determine the EDE rate 150 cm above the floor and ground from the skyshine component for locations inside and outside building 214 respectively. The geometry was modeled such that two MFPs of air extended above/around the ground plane past the 150-meter tally location. Particles that traveled past these two MFPs were killed.

For all calculations, PD cards were used to ensure particles did not contribute to tally locations from cells whose contributions had been previously determined. For the GFIA, NFIA and High GBI rooms, the only particles that were allowed to contribute to the tally locations were those that escaped the roof and north wall. For the High GBI room, the skyshine contribution was determined separately in order to increase the statistical precision of the problem. For the NFIA and High GBI room, a cylindrical weight window mesh generator was used to generate importance functions. As previously explained in the transmission calculations, cells not directly contributing to the tally were modeled as two MFPs thick. After traveling two MFPs, these particles were killed.

C. Maze Transmission/ Streaming
A type F2 Tally was used to determine the EDE rate at the maze entrance and was segmented in the same manner as the F2 tallies in the transmission calculations. Particles that traveled two MFPs in any structure (e.g. shield walls, floor, ceiling, etc.) not including the maze were killed. The EDE rate at the maze entrance was determined separately for the transmission and scatter components.

To determine the EDE rate from the transmission component, a thin zero-importance cell was placed at the maze exit into the calibration room. Therefore any particles scattering into the maze from the calibration room were killed. The maze walls and covers were segmented into smaller cells with increasing importance functions to maintain the particle population approximately equal as particles were transmitted through the maze to the tally location. See Figure 2.

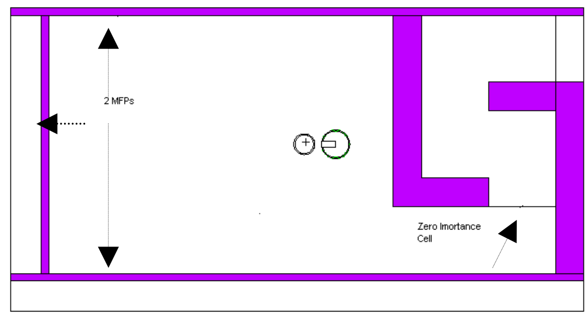

Figure 2: Plan View of GBI Room with Zero Importance Cell for Transmission Calculation.

To determine the EDE rate from the streaming component, the maze walls and covers were segmented such that there were two MFPs of concrete on the front, back and sides of the maze walls and covers. This constrains phase space while ensuring that the scatter contribution of these surfaces is adequately sampled. A zero importance cell was placed between the two MFPs on all sides to kill particles that were transmitted that deeply into the maze shield wall. See Figure 3.

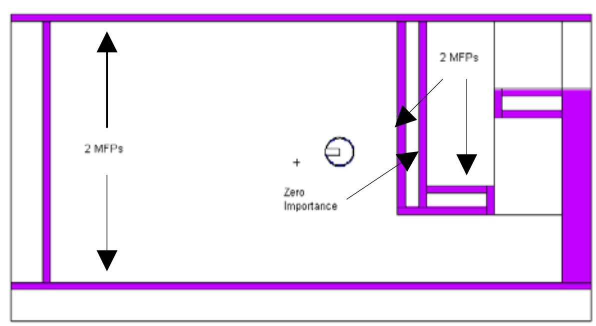

Figure 3: Plan View of GBI Room with Zero Importance Cell for Scatter Calculation.

IV. MEASURED DATA
To determine the EDE rate at near background levels, a pressurized ion chamber (Reuter Stokes) was used to measure the photon contribution and a Wide Energy Neutron Detector Instrument (WENDI) was used to measure the neutron contribution. An ionization chamber survey meter and a conventional Rem

Meter were used to measure photon and neutron contributions respectively at levels significantly greater than background. Only those results greater than 1 μrem/h and 5 μrem/h (once normalized to the actual source term) for the photon and neutron contributions respectively were measured since these are approximately the Lower Limit of Detection for the instruments used. Skyshine measurement verifications were only taken at the 25-meter location east of TA-36-214.

V. RESULTS

Calculated (MCNP™) and measured results are reported below in Tables 1, 2, and 3 for operations occurring in the NFIA, GFIA and High GBI rooms, respectively. For neutron (n) EDE rate calculations, the capture gamma (n,γ) EDE rate is only reported if the contribution is greater than 9.26 μrem/h-Ci (1 μrem/h when normalized to maximum source strength).

Note: In Tables 2, 3, and 4 below:

- *Trans*. denotes Transmission Component;
- *SS* denotes Skyshine Component; and
- C.S. denotes Control Station.

Table 2: EDE Rates From NFIA Operations

	Calculated (μrem/h-Ci)		Measured (μrem/h-Ci)
	Trans.	*SS*	
NFIA C.S.	5.56e2 n 9.26e1 n,γ	1.02e2 n	5.53e2 n 9.55e1 n,γ
Maze Opening	2.69e2 n 1.85e1 n,γ	1.02e2 n	4.08e2 n NA[a] n,γ
GFIA Rm.	8.33e1 n 2.78e1 n,γ	1.18e3 n	1.60e3 n NA[a] n,γ
25 m East	NA	2.22e2 n	2.23e2 n

Agreement between the calculated and measured results is approximately ± 20%.

Table 3: EDE Rates From GFIA Operations

	Calculated (μrem/h-Ci)		Measured (μrem/h-Ci)
	Trans.	*SS*	
GFIA C.S.	1.20e0	1.30e0	6.05e-1
Maze Opening	1.70e0	1.30e0	9.29e-1
NFIA Rm.	1.0e-1	1.88e1	1.02e1
GBI Rm.	4.30e0	9.00e-1	1.99e0
25 m East	NA	8.00e0	4.19e0

Comparisons between the calculated and measured results indicate that all of the calculated results are approximately a factor of two higher than the measured results with the exception of the measurement taken at the GFIA control station. At the GFIA control station, the calculated result is a factor of 4.13 times greater than the measured result.

Table 4: EDE Rates From High GBI Operations

	Calculated (μrem/h -Ci)		Measured (μrem/h-Ci)
	Trans.	*SS*	
GBI C.S.	NA[a]	NA[a]	NA[b]
Maze Opening	3.77e-3	NA[a]	2.04e-3
GFIA Rm.	5.22e-2	2.52e-3	1.92e-2
Beam Stop	3.35e0	NA[a]	1.81e0
25 m East	NA	2.52e-3	1.25e-3

Comparisons between the calculated and measured results indicate that all of the calculated results are approximately a factor of two higher than the measured results.

VI. CONCLUSIONS

MCNP-4C[1] was successfully used to determine the shielding requirements for the CHPCF to meet design objectives. Conservative assumptions were made during the shield design to ensure design objectives were met. Actual measurements, when practicable, were taken to verify shielding calculations and design objectives.

For neutron verification measurements, calculations are approximately ± 20% of measurements. This discrepancy could be associated with two different issues. First, the actual neuron measurement device has an error associated with it of approximately 20% near background (μrem/h) levels. Second, an aluminum platform in the NFIA room was not modeled. This platform may have had a small affect on the transport of neutrons to the tally locations.

For photon verification measurements, all calculations are conservative relative to the actual measurements. Most calculation results are approximately a factor of two higher than actual measurement results. This factor of two may be primarily due to not modeling the rebar

< 1 μrem/h when normalized to actual source strength

[b] < 1 μrem/h

in the concrete shield walls. The largest discrepancy between photon calculation and measurement results is a factor of 4.13 at the GFIA Control Station from GFIA operations. This discrepancy may be larger than that of other verification measurements due to adding approximately equal contributions from the transmission and skyshine components (1.2 and 1.3 μrem/h-Ci respectively) together, which were calculated at different locations. The transmission component was determine by an F2 tally on contact with the shield wall while the skyshine component was determined with an F5 tally at a location four feet from the outer shield wall 150-cm above the floor plane. Again, EDE rates were determined in this manner to be conservative to ensure design objectives were met.

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