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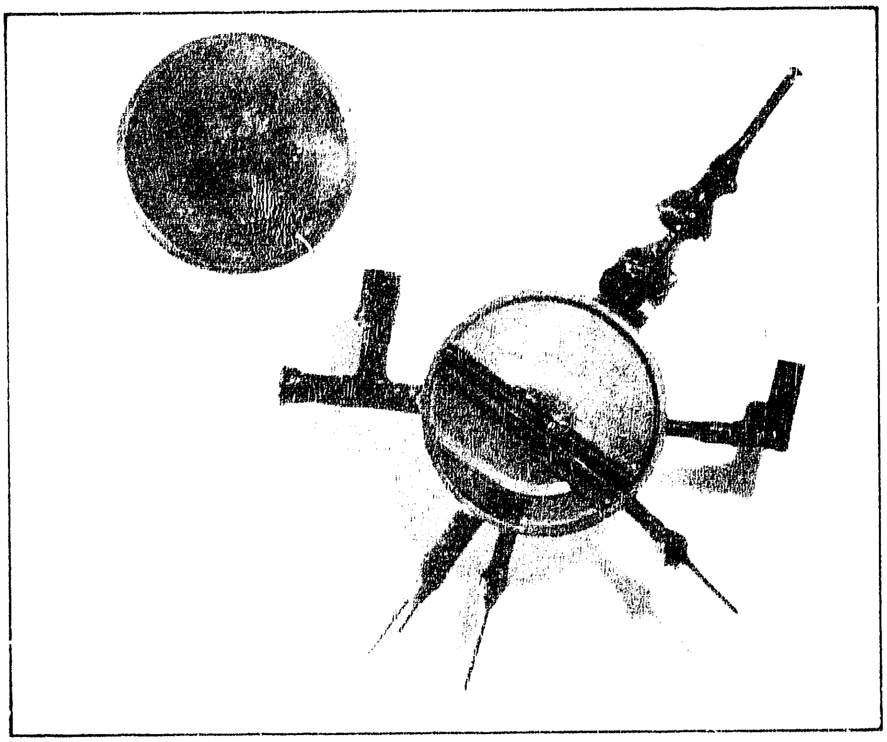

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NEUTRON SKYSHINE FROM END STATIONS OF THE CONTINUOUS ELECTRON BEAM ACCELERATOR FACILITY

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ABSTRACT

The MORSE_ CG code from Oak Ridge National Laboratory was applied to the estimation of the neutron skyshine from three end stations of the Continuous Electron Beam Accelerator Facility (CEBAF), Newport News, VA. Calculations with other methods and an experiment had been directed at assessing the annual neutron dose equivalent at the site boundary. A comparison of results obtained with different methods is given, and the effect of different temperatures and humidities will be discussed.

I. INTRODUCTION

In the CEBAF facility,[1] Fig. 1, the central instrument will be a high-intensity, 40 W beam power and 100% duty factor electron accelerator with an energy range of 0.5-4.0 GeV, providing three simultaneous beams with correlated energies in three distinct experimental areas identified as End Stations A, B, and C. The stations were developed as concrete domes supported by reinforced concrete walls. They are buried underneath the earth, with only the circular domed roofs rising above the ground level. The roofs are also covered with earth. The radiological exposure to the general public from CEBAF operations will be mainly due to skyshine neutrons exiting through the domed roofs of the experimental areas. The DOE regulatory radiation safety limit for the public is 1 mSv per year.

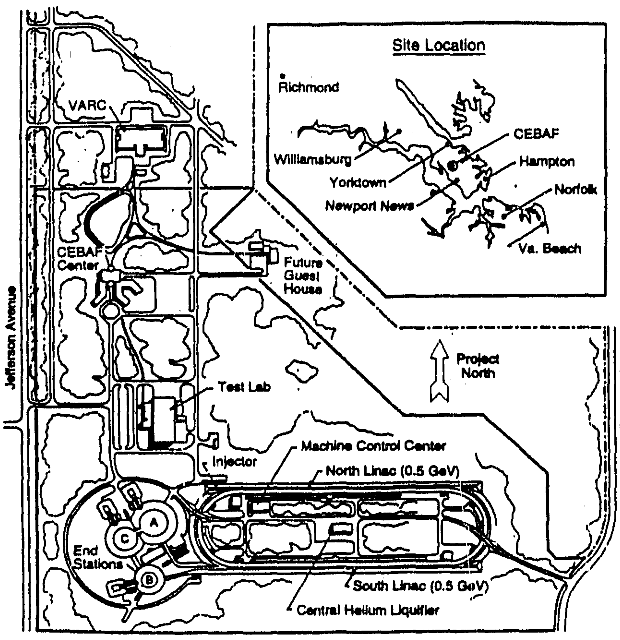
Five different methods, including MORSE-code calculation, have been applied to the estimation of the annual dose equivalent at the site boundary of CEBAF, which is 145 m from the center of end station A. The results of the different methods were compared and found to be in good agreement. With the MORSE code, the effect of air temperature and humidity was also investigated.

II. IMPLEMENTATION OF MORSE CODE

The MORSE code has 37 neutron energy groups ranging from 0.41 eV to 19.4 MeV. In using the code, only general simplifications were made; albedo calculations and Russian roulette games were not included. The input file data give details of the geometry model of the end stations, the locations of estimators and source, and the material for shielding.

A. Geometry Model

The end stations are similar in construction: a concrete cylindrical hall sunk below the ground level, and a concrete circular dome above the ground covered with soil. In Fig. 2, the combinatorial geometry of ES A is shown to consist of seven regions, as follows:



(Courtesy of CEBAF)

Fig.1 CEBAF's Site Plan

1. Walls and floor, both with a concrete thickness of 76.2 cm (2.5 ft). Calculations were made for a density of the walls and roof of 2.3 g cm^{-3}.
2. A concrete inner dome roof, 25.4 cm (10 in) thick.
3. An outer dome roof of CEBAF soil, 1 m thick, with a density of 2.0 g cm^{-3} and containing 26% water by weight.
4. A region of impervium beneath the end station. This region cannot contribute to the calculated dose equivalent.
5. The volume of air within the end station.
6. The volume of air above the end station.
7. A region comprising 1 meter of CEBAF soil for the simulation. This region can be redefined (asimpervium, for example) to study the contribution of the surrounding soil on the estimate of dose equivalent.

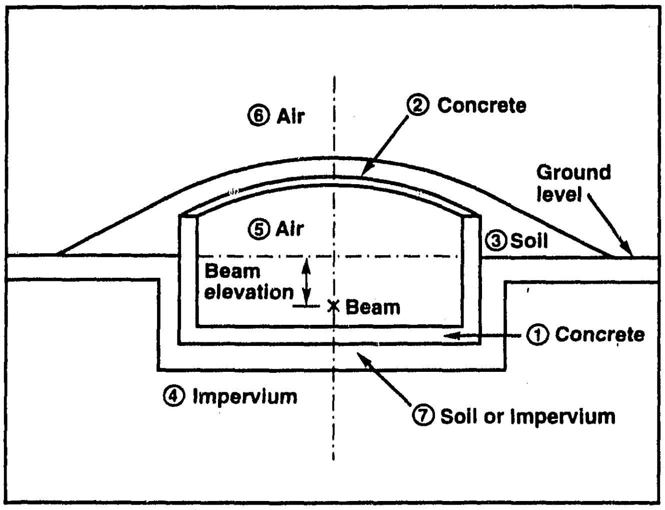


Fig.2 Schematic regions of End-station A.

The multigroup cross-sections for the media used in the various geometry regions were availablefrom ORNL (1979)[2] and Stanford Linear Accelerator Center (SLAC)[3]. In Table 1, specifications of the three end stations are briefly listed.

Table 1. Geometrical Specifications for End Stations.

End station	A	B	C
Hall diameter (m)	56.4	30.5	45.7
Building height (m)	23.5	15.5	14.5
Dome inner radius (m)	65.3	36.3	53.3
outerradius (m)	66.3	37.3	54.0
Dome height (m)	6.4	3.4	5.2
Concrete shield thickness (m):			
Floor	0.76	0.76	0.76
Wall	0.76	0.76	0.76
Dome atcenter	0.254	0.152	0.23
at spring line	0.457	0.279	0.432
Earth shield thickness (m):	For all end stations		
Walls	4.57 m at spring line with 1.5/1 slope of berm to grade.		
Roofs	1.0 m at center and 2.0 m at edge.		

B. Method of Calculation

To estimate the contribution of neutrons from interactions of giant-resonance neutrons inside the end stations and above the roofs to the dose equivalent at distances up to one kilometer from the source, point detectors were selected as estimators set up at given locations on the ground level. The horizontal distances from the center axis of the cylindrical hall of end station A were 44, 67, 95, 190, 457, and 1000 m, respectively. At the same center axis but 6.5 m below the outside ground level, a target with giant-resonance spectrum was chosen as a point source. The MORSE code was started with 100 neutrons and run for at least 100 batches. The results are acceptable if the fractional standard deviation (FSD) is less than 15%.

III. RESULTS

In the MORSE result, the dose equivalents at each estimator were presented in terms of mSv per neutron. The annual dose equivalent at different locations surrounding the CEBAF complex could be evaluated by assuming:

- an average beam power rate of 40 W continuous foroneyear,which is the sum of the beam-power dissipation for all three end stations, and
- a neutron yield of $1.18 \times 10^{12}\ s^{-1}\ kW^{-1}$, which was used for giant-resonance neutrons from a target of copper (see IAEA-188, page 87).

A. Calculation of End Station A

The giant-resonance neutron dose equivalent due to skyshine as a function of distance from the center of the end station was appropriately increased by 30%[4] to partially account for the contribution from mid- and high-energy neutrons. This adjustment estimates the effect of scattering in the dome but does not take into account the contribution due to air scattering in the atmosphere above the dome. This additional contribution is thought to be small compared to the contribution from giant-resonance neutrons at the site boundary. As such, these calculations serve to set a lower limit (i.e., underestimate) to the expected dose equivalent at the site boundary under the assumption mentioned above. Figure 3 shows the annual dose equivalent as a function of distance from the center of end station A. At 145 m from the center of end station A, the neutron dose equivalent was estimated to be 25 μSv per year.

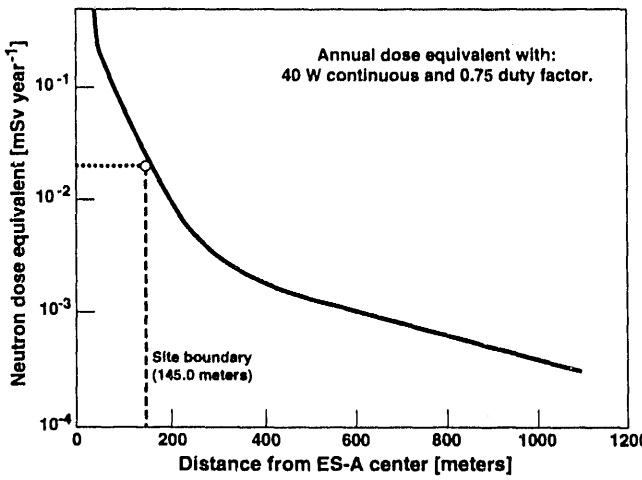


Fig.3 Annual dose equivalent as function of distance

B. Calculations of End Stations B and C

Calculations of dose equivalents from end stations B and C have also been carried out, with a beam power of 40 W for each station,using the same number of point detectors set at the same locations as for end station A, but having the target for each end station set on the proper position. The MORSE calculated dose equivalent values, Sv n^{-1}, for end stations B and C, respectively, are much smaller than for end station A (Fig. 4). The values from end station A will thus be used for the comparison with those obtained from other methods.

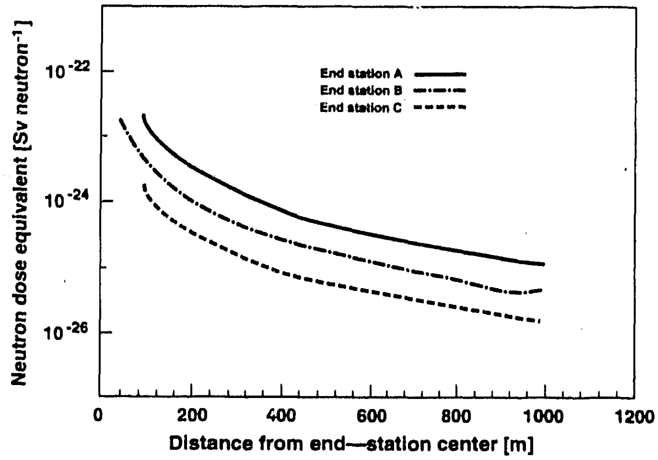


Fig. 4 Comparison of dose equivalents obtained from end stations A, B and C with giant resonance source, (Dry air condition)

C. Comparison with Different Methods

Calculations of different methods[5] have been carried out to estimate the annual dose equivalent at the site boundary of CEBAF, which is 145 m from center of the end station A. They are:

1. Thomas and Stevenson formula (Stapleton, 1988);
2. Importance function method (Stapleton, 1988);
3. Analytical neutron diffusion calculations (Barbier, 1987);
4. Lindenbaum method (Jenlans, 1988);
5. MORSE_CG Code (Sun, 1988).

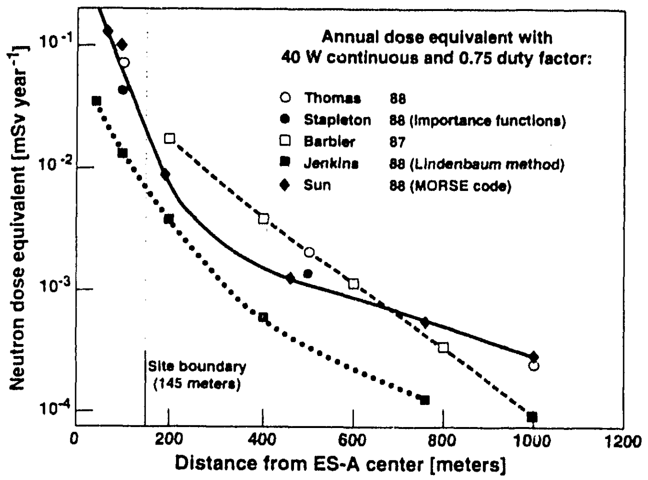


Fig.5 Comparation of annual dose equivalents obtained with different methods.

The agreement between the five results was better than a factor of 3 (Fig. 5). For an assumed 40-watt mean source term, the predicted dose equivalent rates were from 20 to 50 μSv y^{-1}, which may be compared with the design goal of 100, μSv y^{-1}, the DOE reporting level of 250 μSv y^{-1}, and the DOE long-term annual limit of 1 mSv y^{-1}.

D. Effect of Air Conditioning

The air conditioning inside the end stations of CEBAF was set at 23.3°C (74°F) with 45% relative humidity. For the end station A, MORSE was run for 3 air conditions: dry air at 0°C (32°F) with 0% humidity, 23.3°C with 45% humidity, and 37.7°C (100°F) with 100% humidity. The results are shown in Fig. 6. They demonstrate that at a higher percentage of humidity in the air, the dose equivalent decreases, probably due to the scattering of more hydrogen molecules in the air.

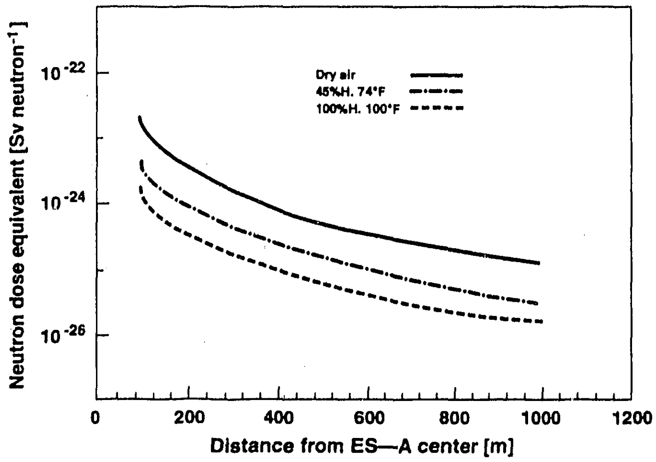


Fig. 6 Comparison of dose equivalents obtained from end stations A with different air conditions in temperatures and humidities.

IV. CONCLUSION

The MORSE code was used for the calculation of the annual neutron dose equivalent from the CEBAF end stations. The results are comparable to those obtained with other methods. It is a reliable computer code with sound theoretical bases, and is suitable for use in solving many type of complex shielding problems that are difficult to perform with empirical formulas.

ACKNOWLEDGEMENT

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