APPLICATION OF MORSE TO RADIATION ANALYSIS OF NUCLEAR FLIGHT PROPULSION MODULES

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Several modifications and additions were made to the multigroup Monte Carlo code MORSE to implement its use in a computational procedure for performing radiation analyses of NERVA Nuclear Flight Propulsion Modules. These changes include the incorporation of a new general geometry module; the inclusion of an expectation tracklength estimator; and the option to obtain source information from two dimensional Discrete Ordinates calculations. Computations comparing MORSE and a point cross section Monte Carlo code, COHORT, were made in which a coupled Discrete Ordinates/Monte Carlo procedure was used to calculate the gamma dose rate at tank top locations of a typical propulsion module. The dose rates obtained from the MORSE computation agreed with the dose rates obtained from the COHORT computation to within the limits of the statistical accuracy of the calculations.

Several modifications and additions were made to the multigroup Monte Carlo code, MORSE(1), to implement its use as a computational procedure for performing radiation analyses of NERVA* Nuclear Flight Propulsion Modules. These changes include the incorporation of a new general geometry module; the inclusion of an expectation tracklength estimator in the analysis portion of the code; and the option to obtain source information from two dimensional Discrete Ordinates calculations to allow coupled Discrete Ordinates/Monte Carlo analyses.

A new general geometry module, patterned after the geometry routines used in the FASTER Monte Carlo program(2), was incorporated into MORSE to facilitate the modeling of complex geometric configurations. As a result of several added features of the new geometry module, the mathematical modeling of systems is made simpler than that of the O5R general geometry routines presently available with MORSE. These features, which reduce the amount computer input and hand calculation required of the user, include:

1. Simple input formats for describing commonly used geometric surfaces such as planes, cones, cylinders, and ellipsoids, along with a generalized quadratic input format.

2. Computer calculation of the ambiguity indices which describe the sign of each region with respect to the surfaces which bound it.

3. Computer check for reflected boundaries, multiple defined regions, and holes.

4. Elimination of the zone, block, sector concept for tracking particles with computer calculation of the probable region that a particle will enter upon crossing a given boundary of a region.

A new analysis routine employing an expectation tracklength estimator was added to MORSE in order to calculate the uncollided and total tracklengths within each region for each energy group. From this information the flux and flux dependent quantities can be calculated with a knowledge of the volume of the region.

Each source ray and post collision ray generated during the random walk is extended through the system until an outside boundary is encountered. The estimator will then score the expected tracklength in those regions intercepted by the ray. In material regions, the expected tracklength is the quantity

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$$\frac{We^{-\rho}\,(1-e^{-\Sigma_T S})}{\Sigma_T}$$

where W = the source or post-collision weight

ρ = total mean free paths from source or collision point to the point on the boundary of the region intercepted by the ray ($\rho = 0$ if source or collision point occurs in the region)

S = total length of ray in the region

Σ_T = total cross section of the region for the particle.

If the region intercepted by the ray is a void, the quantity

$$SWe^{-\rho}$$

is scored.

At the option of the user, the coordinates, direction cosines, energy group, and weight of particle at the outside boundary can be saved on tape to provide a leakage source for another Monte Carlo calculation or for discrete ordinates coupling (described later).

There are two advantages to using this type of volume detector as compared to point detectors employing last collision estimators. First, the radiation environment throughout the entire system can be calculated instead of at a few points, and secondly, the unscattered flux is estimated without the assumption of an isotropic source. On the other hand, the tracklength estimator may give large variances in regions extended from high scattering areas since the percentage of tracklengths which score is reduced.

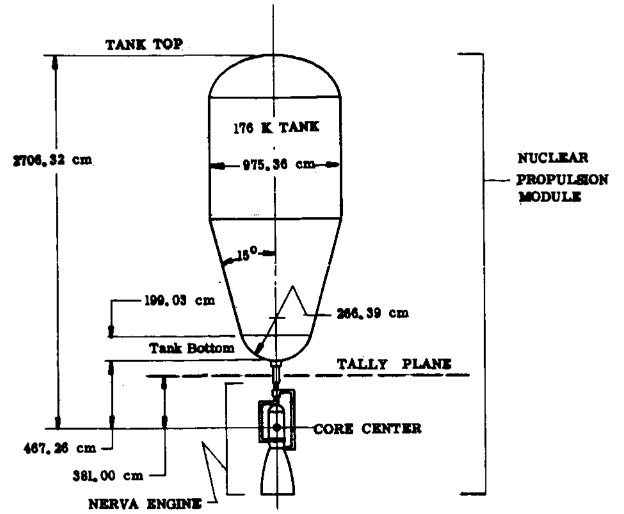
Provisions were made in MORSE to allow input of source data generated from the two dimensional discrete ordinates code, DOT(3). In many shielding problems, the system to be analyzed contains adjacent high/low density regions and it is economical to use S_n discrete ordinates in the high density regions and Monte Carlo in the low density regions. This situation prevails in the nuclear propulsion modules whose entire radiation environment must be calculated, i.e., both in high density regions like the pressure vessel and reactor assembly (PVARA) and external disk shield and in adjacent low density regions like the nozzle assembly and hydrogen tank.

The angular flux data from DOT is transformed to source data for MORSE by the coupling code, DASH(4). DASH converts the DOT output to suitable source particle parameters for MORSE at specified surfaces, which may or may not be identical to DOT leakage surfaces. Furthermore, the leakage data provided by the new analysis routine added to MORSE can be transformed by DASH to source data for a subsequent DOT calculation in another region of the system if desired.

By using the same cross section group structure in MORSE that was employed in DOT, the total radiation environment calculated from the DOT-DASH-MORSE (no pun intended!) computation is based on a consistent cross section set, and has been carried out in each region by the most suitable method.

A check calculation of MORSE with the new geometry and analysis routines was performed using the DOT-DASH-MORSE computational procedure to the calculate tank top dose rate due to the gamma source from the pressure vessel and reactor assembly (PVARA) of a nuclear propulsion module employing a 75K lb thrust NERVA engine and an unshielded 176,000 lb LH_2 capacity tank with a 15° half angle conical bottom. The configuration is depicted in Figures 1 and 2.

The PVARA gamma sources(5) were input to DOT which calculated the flux within the PVARA. The leakage fluxes from the PVARA obtained from DOT were transposed to Monte Carlo source information and transported to the tally plane (Figure 2) by DASH.



NUCLEAR PROPULSION MODULE CONFIGURATION
Figure 1

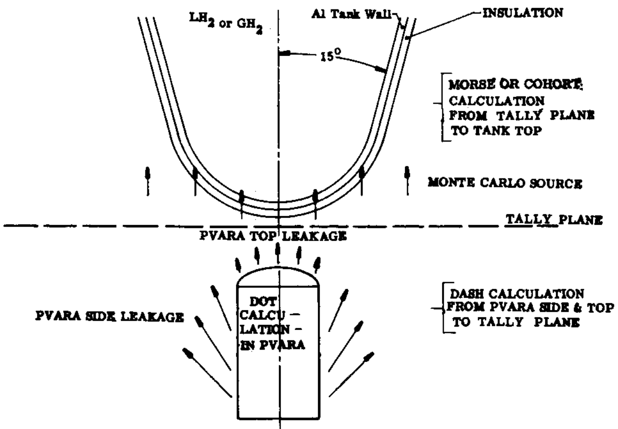


FIGURE 2 COMPUTATION MODEL, PVARA AND TANK BOTTOM

Then, MORSE performed the transport analysis from the tally plane to tank top (Z = 2706 cm). Two runs, one with the tank empty, that is, containing only gaseous hydrogen, and the other with the tank filled to 62,000 lbs LH_2, were made.

Thirteen group, P_6, cross sections for the energy range .1 Mev to 10 Mev were used in the DOT and MORSE calculations. The empty tank case was run without game biasing. However, for the case with the tank filled to 62,700 lbs LH_2, Russian roulette was played in order to prevent generating costly low weight collisions in the liquid hydrogen. Furthermore, an exponential transform was applied to bias the collision density toward the top of the liwuid hydrogen.

A similar calculation using the point cross section Monte Carlo code, COHORT(6), for the Monte Carlo portion from the tally plane to tank top was performed to check the results obtained from MORSE. This computation used last flight estimators to calculate the scattered radiation at two tank top points, one located on axis and the other at a radius of 500 cm. An expectation tracklength estimator was used to calculate the unscattered radiation. Physically, one expects little variation of the scattered radiation at tank top as a function of radius, and thus the dose at tank top locations was obtained as the sum of the unscattered radiation plus a scattered component interpolated between the two points at which the scattered radiation was calculated.

The results of the MORSE and COHORT computations for the two cases are presented in Figures 3 and 4. The results of the empty tank case show excellent agreement in the dose calculated by MORSE and COHORT, while the results for the 62,700 lb LH_2 level show a fluctuation of the dose calculated by MORSE about the dose calculated by COHORT.

In the empty tank case, scattered radiation contributes only about 15% of the total dose, thus better agreement between two Monte Carlo methods would be expected than that in the 62,700 lb LH_2 case, where scattered radiation contributes about 60% of the total dose. The fluctuation of the MORSE results for the 62,700 lb LH_2 case compared to the COHORT results occurs because of the higher variance estimator used in the MORSE computation.

A comparison of the standard deviation, computation time and efficiency of the MORSE and COHORT results is presented in Table 1. The efficiencies are comparable for the empty tank case since the increase in computation time for the COHORT run is balanced by a decrease in standard deviation. For the 62,700 lb case, the MORSE calculation was performed with one-third less computer time than the COHORT calculation. However, the standard deviation of the MORSE answers were of the order of a factor 1.5 higher than that of the COHORT results. The extra time of COHORT runs was expended mainly in estimating the scattered radiation which results in a subsequent reduction in the variance. However, the efficiency as shown in Table 1 for the 62,700 lb LH_2 runs were still comparable. This indicates that standard deviations of the order of those resulting from the COHORT calculations would obtain from MORSE calculations if the number of histories used in the MORSE runs was increased till the computer time used in the calculation was equal to that of the COHORT runs.

These Monte Carlo comparisons have shown that the use of MORSE with a tracklength estimator in a coupled Discrete Ordinates/Monte Carlo calculation can give good agreement with comparable efficiency to the point cross section code, COHORT. Several

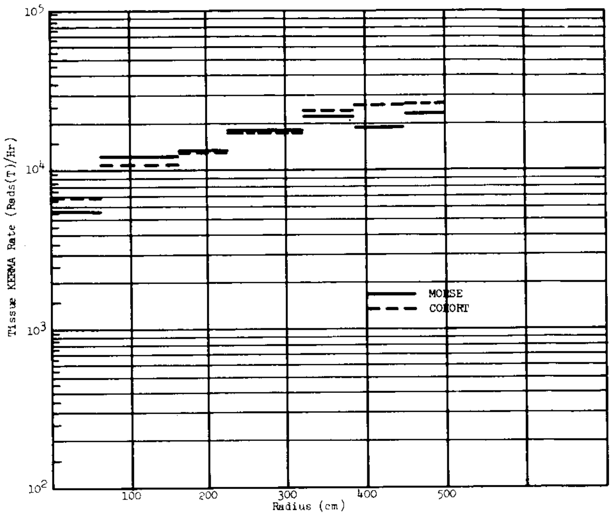


FIGURE 3. PVARA KERMA RATE AT TANK TOP WITH GH_2 ONLY

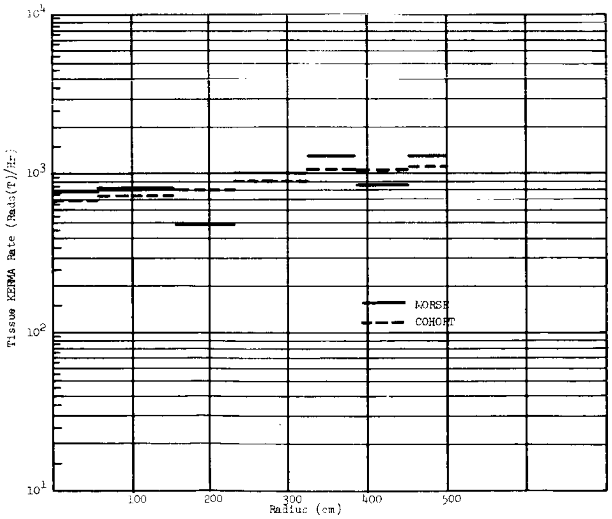


FIGURE 4. PVARA KERMA RATE AT TANK TOP WITH 62,700 LBS. LH_2

additional features of MORSE including the ability to perform coupled neutron/gamma-ray calculations, the use of extensive source and game biasing, and the inclusion of the albedo option may make MORSE an attractive alternative to conventional Monte Carlo codes.

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