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X APPLICATION OF MONTE CARLO TECHNIQUES IN
STRUCTURAL ANALYSIS FOR A NUCLEAR ROCKET

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ABSTRACT

The application of Monte Carlo techniques in the structural analysis of the NERVA nuclear rocket engine reactor is discussed. This unique application of gaming techniques begins with a statistical description (i. e., mean and standard deviation) of the significant input parameters in the nuclear-thermal-structural analysis chain. With the assistance of a random number generator, random values can be selected for a complete set of input parameters and a Monte Carlo case can be calculated. From a series of such cases, statistically defined output parameters are obtained. A "weighted" Monte Carlo approach is followed, currently assuming normal distribution throughout but conveniently adaptable to any cumulative density function that available data might support. The convergence to a stable solution within a relatively small number of random trials is graphically demonstrated for representative component stress calculations.

NOTE: The Nuclear Engine for Rocket Vehicle Applications Program (NERVA) is administered by the Space Nuclear Propulsion Office (SNPO), a joint office of the U. S. Atomic Energy Commission and the National Aeronautics and Space Administration. Aerojet Nuclear Systems Company as prime contractor for the engine system and Westinghouse Electric Corporation as subcontractor for the nuclear subsystem, are developing a nuclear propulsion system for space applications.

The incorporation of probabilistic methods in mechanical component design, as described, for example, by Haugen¹, is a relatively new engineering innovation. The expense of testing the NERVA nuclear rocket engine for reliability has provided a compelling incentive to incorporate such probabilistic theory into the day-to-day activities of the stress analyst. One pace-setting development within the NERVA core analysis not exclusively related to graphite components, but judged to be of significant interest to this audience, is the application of Monte Carlo (random trial) techniques. This unique application of gaming techniques begins with a statistical description (i.e., mean and standard deviation) of the significant input parameters in the nuclear-thermal-structural analysis chain. With the assistance of a random number generator, random values can be selected for a complete set of input parameters and a Monte Carlo case can be calculated. From a series of such cases, statistically defined output parameters are obtained. This process is shown in block diagram form in Figure 1.

A "weighted" Monte Carlo approach is followed, currently assuming normal distribution throughout but conveniently adaptable to any cumulative density function that available data might support. The particular structural analysis model to which the Monte Carlo approach is applied is the so-called RATS program. The RATS model is essentially a gross representation of the NERVA nuclear subsystem which calculates intercomponent loads and displacements and selected component stresses. The primary purpose of the RATS analysis is to provide boundary conditions for the detailed component analysis. The results are also suitable for showing general subsystem trends in system parametric trade studies. The Monte Carlo analytic package consists of a nominal RATS analysis and 14 off-nominal random trials. The choice of the number of trials is a cardinal decision in planning a Monte Carlo analysis. The dependability of the results favors a multitude of random trials (computer cases) while practical considerations, like computer expense, favor a minimum number of runs. The following five figures, selected to represent the best, worst and typical situations, demonstrate the reasonable convergence to a good solution for the probabilistic description of an output parameter as a function of the number of Monte Carlo trials. The presence of an occasional "maverick" should not be entirely disconcerting because such anomalies are always statistically possible. Recall that the calculations are for a 95%, not 100%, confidence level.* The conclusions drawn after about a year of effort with these Monte Carlo calculations is that statistical calculations which are extremely useful to the design and reliability prediction processes are possible with moderate investment of computational resources.

*Some compromise of mathematical rigor in the confidence level calculations is admitted.

REFERENCES

1. Edward B. Haugen, Probabilistic Approaches to Design, John Wiley and Sons, Inc. New York (1968).

Fig. 1. Schematic of Monte Carlo Structural Analysis.

Fig. 2. Axial Load of Top of Outer Reflector.

Fig. 3. Inner Reflector Q''' Radial Stress at Midband.

Fig. 4. Inner Reflector $E \Delta T$ Axial Stress at Midband.

Fig. 5. Average Fuel Element Elongation.

Fig. 6. Average Fuel Element Axial Displacement.