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INTRODUCTION

The SCALE (Standardized Computer Analyses for Licensing Evaluation) code system [1] includes a comprehensive package of tools for sensitivity/uncertainty (S/U) analysis [2]. The TSUNAMI computation sequences in SCALE have been widely used for criticality safety and reactor physics applications that require eigenvalue solutions of the neutron transport equation. Recently, a prototypic version of TSUNAMI was developed for S/U analysis of coupled neutron-gamma (n-γ) calculations with external volumetric or surface sources. The work provides the more general capability to address photon-dependent responses such as gamma dose and nuclear heating that are of interest in shielding applications like ex-core detector analysis, design of fuel reprocessing plants, fusion systems, and space-nuclear studies.

This paper describes the techniques implemented in TSUNAMI to compute sensitivity coefficients for coupled n-γ calculations. The sensitivities are combined with nuclear data uncertainties from the SCALE covariance library to determine the uncertainty in photon responses. Sensitivity results are presented for several responses in a space reactor shield design.

SENSITIVITY COEFFICIENTS FOR COUPLED n-γ PROBLEMS

Photon responses are generated by gammas (or their progeny) emitted from an external source or created by neutron interactions such as fission, capture, or inelastic reactions. Sensitivity coefficients for photon responses are computed in a manner similar to that for neutron responses such as k_{eff}; i.e., using first-order perturbation theory expressions that contain forward and adjoint flux distributions. Our initial effort has focused on modifying the TSUNAMI-1D computation sequence [3] to (a) perform fixed-source forward and adjoint n-γ transport calculations with the SCALE 1D discrete ordinates code XSDRNPM, (b) utilize the solutions to compute sensitivity coefficients for coupled n-γ data, and (c) combine the sensitivities with data covariances to determine the uncertainty in photon responses.

Neutron and gamma fluxes are calculated using a coupled N-G multigroup library in which groups $1 \rightarrow N$ correspond to neutrons and groups $N+1 \rightarrow N+G$ correspond to photons. Hence, the library contains total and partial cross-section data for both neutrons and photons. The multigroup transfer matrix contains scattering cross sections for transfers between two neutron or gamma groups, respectively, as well as secondary gamma production terms, which are represented by transfers from neutron to gamma groups. The latter typically consists of neutron interaction cross sections multiplied by energy-dependent gamma yields. S/U analysis for coupled calculations must include photon interaction and production data in addition to the usual neutron data previously addressed in TSUNAMI. Also, it should be noted that for coupled calculations the sensitivity expressions for neutron interaction data such as capture, fission, inelastic scatter, etc., are different from the expressions used in criticality analysis, since a perturbation in the neutron data may cause a change in the gamma production rate and, consequently, a change in a gamma response. Table I lists some of the new types of nuclear data sensitivities that were added to the TSUNAMI-1D calculation.

TABLE I. New Types of Data Sensitivities for Coupled n-γ Calculations.

Data Type	Reactions
Photon Interaction	Total attenuation, photoelectric absorption, photonuclear absorption, pair production, incoherent scatter (Compton), coherent scatter (Rayleigh)
Photon Production (γ Yield from Neutrons)	Radiative capture; fission; discrete and continuum inelastic scatter; (n,p)-to excited level; (n,d)-to excited level, etc.

APPLICATION TO SPACE REACTOR SHIELDING

The mass of the payload shielding for a space reactor is a critical parameter affecting cost and feasibility of the planned mission. The shield configuration and concomitant mass are impacted by uncertainties in nuclear data used in the coupled n-γ transport calculations performed during the design process. In order to quantify the data sensitivities of several proposed space reactor shield designs for the Prometheus project, S/U calculations were performed with modified version of TSUNAMI-1D. The actual shield configuration corresponds approximately to a truncated cone; however, since the transport calculation in TSUNAMI-1D is limited to 1D geometry, the shield was modeled by a spherical annulus with input lateral leakage losses determined from Monte Carlo calculations of the true 3D geometry. Table II shows some representative nuclear data sensitivities for three responses in a Be-LiH shield.

SUMMARY

The SCALE S/U package was recently extended to compute sensitivities for nuclear data used in coupled n-γ transport calculations. The automated computation sequence is presently based on 1D discrete ordinates calculations but can easily be extended to use higher dimensional transport codes; e.g., TORT[4]. This capability has a wide range of potential applications in shielding and dose assessment.

REFERENCES

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TABLE II. Data Sensitivities for Be-LiH Shield.

Response	Data Parameter	Sensitivity Coefficient
Φ > 1MeV	H-1 (n,n) elastic	-3.7697E+00
	Li-7 (n,n) elastic	-2.2673E+00
	Li-7 (n,n') inelastic	-1.4569E+00
	Be-9 (n,2n)	-1.0971E+00
Si Kerma	H-1 Compton scatter	-3.5524E-01
	Li-7 Compton scatter	-9.8349E-01
	Be-9 (n,n) elastic	-6.3780E-01
	Fe-56 Compton scatter	-5.0026E-01
Peak Nuclear Heating	Be-9 (n,n) elastic	1.0217E+00
	B-10 (n,alpha)	-8.6129E-01