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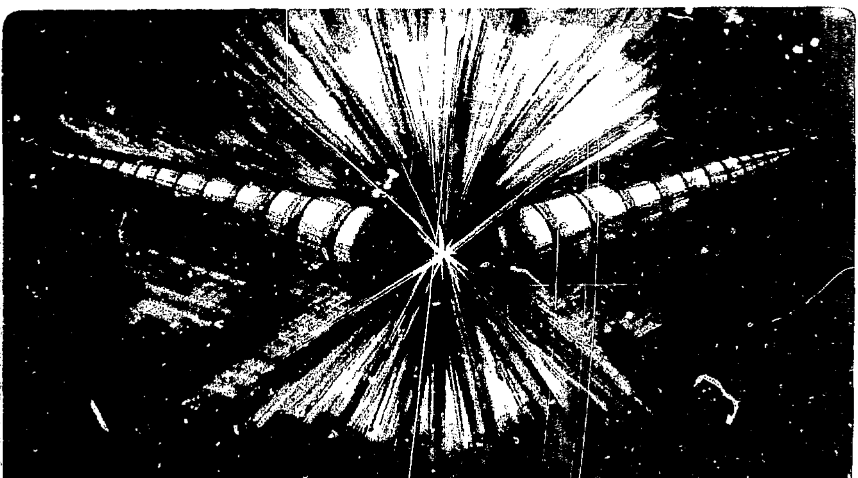

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ACDOS2: A CODE FOR NEUTRON-INDUCED ACTIVITIES AND DOSE RATES*

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Summary

In order to anticipate problems from the radioactivation of neutral beam sources as a result of testing, a code has been developed which calculates both the radioactivities produced and the dose rates resulting therefrom. The code ACDOS2 requires neutron source strength and spectral distribution as input, or alternately, the source strength can be calculated internally from an input of neutral beam source parameters. A variety of simple geometries can be specified, and up to 12 times of interest following the shutdown of the neutron source. Radiation attenuation and daughter radioactivities are treated accurately. ACDOS2 is also of use for neutron-induced radioactivation problems involving accelerators, fusion reactors, or fission reactors.

Introduction

Although it is generally recognized that activation problems will result from several of the large fusion experiments now planned or under construction, it appears that such problems may have to be faced even before such experiments operate. This consequence follows from the fact that neutral-beam design must necessarily precede applications by several years. A forthcoming upgrade program at LBL will require prolonged periods of testing of a deuterium 170-keV neutral beam at 65 A with a 10% duty factor. On a cold self-loaded beam dump, such a beam would generate 2.8 MeV neutrons at an instantaneous rate[1] of about 7.8 x 10^{12} neutrons per second. Such a source can produce appreciable dose rates for personnel who must do a maintenance work following a prolonged period of testing. A survey of several U.S. laboratories determined that there was no code readily available which could easily be adapted to CDC computers, and which would calculate the required dose rates. Thus, a decision was made to construct such a code, using the most modern libraries of neutron-cross-section and radioisotope-decay data available. Our code ACDOS2 has been written in Fortran IV with the intention of making it readily adaptable at other installations, and useful for a variety of neutron-activation problems.

Neutron Intensity and Energy Distribution

In neutral-beam development, periods of testing usually average a few hours, separated by intervals of several hours required for maintenance or overnight shutdowns. ACDOS2 calculates the average neutron source strength during the test periods from data supplied by the user, consisting of the deuteron instantaneous current and the energy, the duty factor during the test period, the length of the test periods, the length of the interval between tests, and the number of test periods. The calculation is based on measured neutron-production rates from self-loaded targets[1] subject to the $^2H(d,n)^3He$ reaction, plus a correction for deuteron energies differing from 150 keV. Alternatively, ACDOS2 makes provision for the user to directly enter the average neutron source strength, for other than neutral-beam-source applications.

ACDOS2 requires a set of group fluxes, together with a list of the corresponding energy boundaries. Fluxes must be normalized to unit neutron intensity, and may be supplied along with other necessary input data, or read in from a tape which has been created by a previous neutron transport code, such as ANISN or MORSE. Fluxes must be normalized to unit neutron production rate.

Calculation of Radioactivities Produced

To calculate the activation rates, ACDOS2 requires the target nuclides to be specified as to atomic number, mass number, and total mass in kg. ACDOS2 treats the targets as homogeneous and neglects neutron attenuation in the tartets. ACDOS2 calls on the ACTL library of experimental neutron cross sections[2], with up to 12 different reactions listed for each target nuclide. ACTL supplies informaion on product identification and half life for both excited-state and ground-state product nuclides. ACDOS2 singles out for consideration all product nuclides with half lives greater than second. For each such product, ACDOS2 determines a continuous range of cross sections by linear interpolation between experimental points.

ACDOS2 uses the group energy boundaries and the group fluxes in order to construct a continuous approximation for the flux (i.e., flux density). The assumption is made that the lowest energy group is a thermal group with a Maxwellian energy distribution, and that the intermediate energy groups all have a 1/E energy distribution. The highest energy group or groups is specified to have an energy dependence for the form Aexp(E/B) since the latter has been found to be a good approximation to the transport-code prediction in the case of a mono-energetic neutron source. Arbitrary constants are assigned by requiring that each flux density produces the proper average, and that flux densities join continuously from group to group. With the continuous flux densities and the continuous cross sections, ACDOS2 then computes an average (flux-weighted) cross section for each energy group and each reaction.

In order to calculate activities, ACDOS2 requires a set of up to 12 time points measured from the end of the last test period. For each product nuclide, ACDOS2 computes the group-produced activity, and then the total for all groups, at the end of the final test period. The latter is then used to determine the activities at the user-specified times, and the results are printed out for each product nuclide.

Geometry and Radiation Attenuation

ACDOS2 requires the user to approximate the geometry of the target as either a point source, a solid sphere, or a cylinder with the observer stationed at a point on the axis. In each case, the

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distance from the observer to the surface must be specified. ACDOS2 also allows the dose rate to be computed as a result of the activation of the shielding walls. In the latter case, the enclosure is approximated as a hollow sphere, and a correction is made for the fact that the flux in the walls is depressed as compared to the flux in the interior.

To determine the annihilation and gamma radiation characteristic of the product-nuclide decays, ACDOS2 searches through the LEVDEC library to determine the identification of the daughter nucleus and the energy level in the daughter, for each mode of decay of the product nucleus. LEVDEC is a subset of the ENSL nuclear data library.[3] ACDOS2 assumes that the gamma rays produced by the daughter have the same energies as the daughter levels which are accessed by beta decays, i.e., the possibility of cascade gamma-ray transitions is neglected. In the case of each positron transition, ACDOS2 augments the gamma-ray list by 2 annihiliation quanta. A second search of the LEVDEC library is necessary to determine whether any of the daughter nuclides are radioactive. If radioactive daughters are found, their activities are computed by taking into accoaunt their buildup from the decay of their respective parents. Radiations from the radioactive daughters are then considered in the same way as from their parents.

The attenuation within the targets is accoaunted for, under the assumption that radioactivity production is uniform within the target, and that analytic formulae using buildup factors can be applied. In the case of the cylinder, the addition of attenuation complicates the analytic formulae to the extent that a truncated-cone approximation was used instead. An option exists which allows the user to neglect the effect of attenuation, if he so chooses. The final result is a calculation of dose rate, at the specified times, summed for each target nuclide, but also broken down as to the contribution of each radioactive product nuclide and each radioactive daughter thereof.

Applications, Availability, and Future Plans

Thus far, ACDOS 2 has been applied to problems of beamdump design, and predicts, for example, that a molybdenum structure would be superior to a copper structure, insofar as activation is concerned. Another result is that a vanadium surface layer has no effect on the overall activation intensities. ACDOS2 has also been applied to the estimation of activities and dose rates from samples irradiated in a fission reactor, where it greatly facilitates the calculations required for the approval of new experiments.

Plans for the future involve another version of the code which will allow the calcualation of specific energy absorption in the target, and which will update the ACTLMFE library to add some nuclides now lacking. A comparison with other existing codes will also be attempted.

ACDOS2 is available on the MFE National Computer Center, and is also available on tape. A rather extensive user's manual also exists[4]. Inquiries should be addressed to the first author above.

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