2. Short and long test decks for the UNIVAC version are stored in Field 1 as a symbolic named DATA/DECK.

3. Program description. Ref. 1.

14. *References:*

[1]JAMES R. SHEFF, User's Manual for NOISY 1—A Program for Calculation of Space Dependent Spectral Densities in Cubical Reactors, BNWL-1260, Battelle Northwest Laboratory (1970).

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PICA

1. Name of Program: PICA, a Monte Carlo intranuclear-cascade code package for medium-energy photon-induced nuclear reactions consisting of the programs PIC, MECCAN, and EVAP.

2. Computers for Which Programs are Designed: IBM 360/75 and 360/91.

3. Nature of Physical Problem Solved: PIC calculates the results of nuclear reactions caused by the collision of medium-energy photons with nuclei.[1,2] The photon energy range in which the calculations are applicable is $30 \lesssim E_\gamma \lesssim 400$ MeV. All target nuclei with mass numbers >4 are possible. The program PIC can accommodate incident monoenergetic photons as well as thin-target bremsstrahlung spectra, thin-target bremsstrahlung difference spectra, and thick-target bremsstrahlung spectra. For the last type of spectra the user must furnish the photon spectral data. PIC writes a history tape containing data on the properties of the particles (protons, neutrons, or pions) escaping from the nucleus. The data consists of the types of escaping particles and their energies and angles of emission. The associated analysis code MECCAN utilizes the data on the PIC history tape to calculate cross sections such as the nonelastic cross section or the doubly differential cross section for energy-angle correlated distributions. EVAP then carries the nuclear reaction through an additional phase, that of evaporation, and calculates the energy spectra of particles (protons, neutrons, deuterons, tritons, ^{3}He, and alpha particles) "boiled off" from the nucleus after the cascade has stopped, evaporation particle multiplicities, and evaporation residual nuclei (radiochemical) cross sections.

4. Method of Solution: The interaction of high-energy photons with nuclei is described by using the intranuclear-cascade and evaporation models. Monte Carlo methods are employed to provide a detailed description of each interaction. The initial interaction of the photon with the nucleus is obtained from the quasi-deuteron model of Levinger, that is, photon absorption by a neutron-proton pair moving within the nucleus or from one of the four pion-nucleon states formed in the photon-nucleon interaction. The effect of secondary nucleon-nucleus and/or pion-nucleus interactions following the photon absorption is accounted for by utilizing the intranuclear-cascade concept of high-energy particle-nucleus reactions. Each particle involved in a collision is traced through the nucleus using the appropriate particle-particle cross sections until the particle escapes from the nucleus or is captured by the nucleus. In all parts of the calculation, the Fermi momentum of the struck particle, the exclusion principle, and the nonuniform density distribution are taken into account. Following the cascade phase, the nucleus is usually in a state of high excitation. This excitation energy can be dissipated through particle emission. This de-excitation is handled by the evaporation model.

5. Restrictions on the Complexity of the Problem: The range of validity of PIC is from 30 to 400 MeV for the energy of the incident photon.

6. Typical Machine Time: The approximate machine time to obtain reasonable statistical accuracy is 30 to 60 min on the IBM 360/75 computer.

7. Unusual Features of the Program: PIC uses an exact sampling technique to determine the collision site and the types of particles in the reaction.

8. Related and Auxiliary Programs: The Nuclear Configuration Code[3] creates a modified nuclear configuration data input tape for PIC. In PIC three nuclear regions are used to approximate a continuous nucleon-density distribution in the nucleus, and the radii of these regions can be changed by using the Nuclear Configuration Code.

9. Status: The PICA code package is being used on the IBM 360/75 and 360/91 computers at the Oak Ridge National Laboratory Computing Center.

10. Machine Requirements: PIC, MECCAN, and EVAP each require ~470K bytes of core. PIC and EVAP require a minimum of two 9-track tape drives in addition to the standard I/O devices. MECCAN requires one 9-track tape drive.

11. Programming Languages Used: The programs are written in FORTRAN IV except for random-number generating subroutines, which are in assembly language.

12. Operating System or Monitor under which Program is Executed: IBM 360 Operating System, Level 18, FORTRAN H.

13. Other Programming or Operating Information or Restrictions: PIC consists of ~6400 source cards.

14. Material Available: The code package is available from the Radiation Shielding Information Center (RSIC) at the Oak Ridge National Laboratory.

15. *Acknowledgments*: This work was supported by the U.S. Atomic Energy Commission under contract with Union Carbide Corporation.

16. *References*:

[1]T. A. GABRIEL, M. P. GUTHRIE, and O. W. HERMANN, "Instructions for the Operation of the Program Package PICA, an Intranuclear-Cascade Calculation for High-Energy (30 to 400 MeV) Photon-Induced Nuclear Reactions," ORNL-4687, Oak Ridge National Laboratory (1971).

[2]T. A. GABRIEL and R. G. ALSMILLER, Jr., *Phys. Rev.*, **182**, 1035 (1969).

[3]H. W. BERTINI, A. H. CULKOWSKI, M. P. GUTHRIE, and O. W. HERMANN, *Nucl. Sci. Eng.*, **46**, 437 (1971).

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VENUS

A Two-Dimensional LMFBR Disassembly Computer Program

1. Name of Code: VENUS.[1]

2. Computer and Programming Language: Written in FORTRAN IV for the IBM 360/75 using the standard OS/360 system and FORTRAN H compiler.

3. Nature of Physical Problem Solved: VENUS computes the power, energy release, and space-time (r-z geometry) history of the temperature, pressure, density, and material motion of a liquid metal fast breeder reactor (LMFBR) during a disassembly excursion. Reactivity feedback due to Doppler broadening and motion of the reactor material is accounted for.

4. Method of Solution: The power and energy release are calculated using the point kinetics formulation of Kaganove with up to six delayed neutron groups.[2] The reactivity is a combination of an input driving function and feedback effects due to Doppler broadening and material motion. An adiabatic model is used to calculate the temperature increase throughout the reactor, based on an initial temperature distribution and power profile provided as input. These temperatures are, in turn, converted to fuel pressures via an energy dependent or energy-density dependent equation-of-state (EOS). In nonfueled regions, pressures are calculated by a simple compression model. The code is structured such that the user can readily add a new EOS if the EOS in the program is not applicable or suitable to the user's requirement. The material motion that results from the pressure buildup is calculated by a direct finite difference solution of a set of two-dimensional (r-z) hydrodynamics equations. This is done in Lagrangian coordinates using a modified version of Kolsky's[3] method. The reactivity change associated with this motion is calculated by first-order perturbation theory. The displacements are also used to adjust the fuel densities as required for the density dependent equation-of-state. An automatic time-step-size selection scheme is provided to control the numerical accuracy of the calculations.[4]

5. Restrictions on the Complexity of the Problem: The code is written so that the dimensions of the storage arrays can be readily changed to accommodate a broad range of problem sizes. In the base version, the total number of mesh points is restricted such that

$$(N_r + 3)(N_z + 3) < 700 \quad .$$

N_r and N_z are the total number of mesh intervals in the r and z directions. The total number of spatial regions used in the mockup is restricted to 20. The program requires about 375K bytes (4 bytes = short word, 8 bytes = long word) of storage with these restrictions. If the available storage is more than 375K, the above restrictions can be relaxed accordingly.

6. Typical Machine Time: The machine time is highly dependent on the nature of the excursion. Typical problems require from 3 to 15 min of IBM 360/75 CPU time, with some cases taking up to 30 min.

7. Unusual Features of the Code: VENUS has the following two distinct advantages over Bethe-Tait type analyses[5-8]:

   a. Because conservation of mass and momentum are explicitly taken into account in the VENUS program, the assumption that the pressure can be calculated by ignoring any change in density during an excursion used in Bethe-Tait type analyses is no longer needed. Since the density is computed explicitly as a function of time, an energy-density-dependent equation-of-state can be employed readily.

   b. The use of Lagrangian coordinates in the VENUS program provides detailed information on the motion of the reactor material during an excursion. This information is essential to the basic understanding of the mechanism of an accident and to the assessment of possible damage to the surrounding structures.

8. Related and Auxiliary Programs: Two auxiliary graphical output programs are available. One is designed for use with the IBM 2280,[9] and the other is for the S-C 4060.[10]

9. Status: In use.

10. Machine Requirements: The base version requires about 400K bytes of storage to execute on an IBM 360. One reason for the rather large storage requirements is that most of the data are stored in double precision. If the code was converted for use on a computer with a more accurate single-precision word size than the IBM 360, it should be possible to use single-precision storage. This would result in decreasing the word storage requirements by about 40%. One peripheral storage device is needed if the graphical output option is used.

11. Material Available: The code, documentation, and a sample problem are available from the Argonne Code Center at Argonne National Laboratory. The code and sample problem require about 3500 cards. For additional information, contact either William T. Sha, Argonne National Laboratory, Argonne, Illinois 60439, or J. F. Jackson, Argonne National Laboratory, Idaho Falls, Idaho 83401.

12. *Acknowledgment:* This work was performed under the auspices of the U.S. Atomic Energy Commission.

13. *References:*

[1]W. T. SHA and T. H. HUGHES, "VENUS—A Two-dimensional Coupled Neutronics-Hydrodynamics Computer Program for Fast Reactor Power Excursions," ANL-7701, Argonne National Laboratory (1970).

[2]J. J. KAGANOVE, "Numerical Solution of the One-Group Space-Independent Reactor Kinetics Equation for Neutron Density Given the Excess Reactivity," ANL-6132, Argonne National Laboratory (1960).