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**ANALYSIS OF FISSILE MATERIAL STORAGE
AND SHIPPING AT THE Y-12 PLANT**

E. C. Crume

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE Y-12 PLANT

operated for the **ATOMIC ENERGY COMMISSION** *under* **U. S. GOVERNMENT** Contract W-7405 eng 26

**UNION
CARBIDE**

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Nuclear Division

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ABSTRACT

Various techniques are utilized in the criticality safety analysis of fissile material shipments and storage at the Oak Ridge Y-12 Plant. In recent years, emphasis has been placed on the utilization of EDPM techniques, especially the newly developed KENO criticality calculational program, to satisfy current technical and economic requirements. While the range of applicability of such techniques already includes most current Y-12 Plant applications, work is in progress to extend it by improving the neutron interaction cross sections used in the criticality calculations.

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SUMMARY

Various techniques are utilized in the criticality safety analysis of fissile material shipments and storage at the Oak Ridge Y-12 Plant.^(a) In recent years, emphasis has been placed on EDPM techniques, especially the newly developed KENO criticality calculational program, because they can be used to meet the most demanding of current technical and economic requirements.

Capabilities of present EDPM techniques have been demonstrated by obtaining satisfactory solutions of many plant storage and shipping problems. In obtaining these solutions, the requirements of effective utilization of plant floor space and satisfaction of AEC shipping regulations were of paramount importance.

(a) Operated by the Union Carbide Corporation-Nuclear Division for the United States Atomic Energy Commission.

INTRODUCTION

Both storage and shipping configurations of fissile units are more or less regular geometrical arrays. Therefore, an understanding of the criticality conditions of arrays of fissile units is fundamental to solving storage and shipping problems that arise in plant environments. The neutronic analysis of arrays is difficult even if the arrays consist entirely of geometrically simple units of solid metal or solution. In plant environments and in shipping, the units are generally geometrically complicated. Furthermore, containers, container supports, room walls and floors, and, frequently, personnel provide varying degrees of moderation and reflection to the arrays. The need to consider contingent conditions, including those required by AECM 0529 for shipping, may also complicate the problem to be solved. Therefore, it is not surprising that relatively sophisticated techniques are required to obtain solutions to storage and shipping problems that are practical and economical.

The purpose of this report is to discuss the development, present status, and plans for improving the more sophisticated techniques being used at the Y-12 Plant for the analysis of fissile material storage and shipping problems. Additionally, some examples are included that illustrate the uses of these current techniques.

ANALYZING FISSILE MATERIAL STORAGE AND SHIPPING

TECHNIQUES FOR ANALYZING STORAGE AND SHIPPING PROBLEMS

General

The foundation upon which all criticality safety analysis is built is the large body of experimental criticality data that exists^(1,2) and which is continually being added to at the various critical experiment facilities. Often it is possible to solve storage and shipping problems (hereafter the modifiers "storage" and "shipping" will usually be dropped) by reference to existing general data such as the results of the "tinkertoy" and related experiments.^(3,4) Additional experiments may be performed on the actual fissile units that must be stored or shipped.⁽⁵⁾ However, it is not always possible to obtain sufficient numbers of either the actual fissile units involved in a problem or even enough "tinkertoy"-type units to perform the experiments. Also, an adequate experimental program may be too time consuming or too costly to solve a particular problem, or there may be programmatic interferences. For these reasons, various forms of analytical techniques have been developed specifically for use in solving problems or have been adapted from reactor analysis techniques. An excellent, relatively current summary of techniques used in the field is contained in the document: "Proceedings of the Livermore Array Symposium".⁽⁶⁾

The approach used at the Y-12 Plant to solve a criticality safety problem is to apply the simplest, least-time-consuming, and least-expensive technique that will solve the problem consistent with its associated technical, timing, and economic requirements. Adequate solutions to some problems are obtained from existing experimental data or empirical generalizations of those data. Other problems may require the use of existing hand calculational techniques such as the solid-angle method⁽⁷⁾ or the density-analog method.⁽⁸⁾ More difficult problems may require the use of more or less sophisticated EDPM techniques such as the ANISN⁽⁹⁾ and KENO⁽¹⁰⁾ criticality calculation programs. Some problems may be sufficiently difficult, or technical and/or economic requirements may be altered enough, to require the development of new analytical techniques. Problems of this latter type may also generate the need for critical experiment programs either to provide adequate validation of the new techniques; or, if no technique with adequate accuracy can be devised, to provide solutions to the problems. The following discussion will be limited to techniques needed to solve the more difficult type of problem.

The KENO Program

General - Actually, the KENO program previously referred to is a relatively new analytic technique that has been and continues to be developed to meet the more stringent technical and economic demands that have arisen in the past few years. In principle, KENO can be used to accurately find the criticality condition of any

arrangement whatsoever of any type of fissile material. In practice, its accuracy is limited by the correctness of the neutron interaction cross sections which are part of the input to the program.

The inherent accuracy of KENO is due to the method used in it to determine the behavior of the neutrons in a reacting system; that is, how KENO treats the neutronics of a reacting system. The method used is a statistical one called the Monte Carlo method.⁽¹¹⁾ In this method, "life histories" of a limited number of individual neutrons are followed as they travel from place to place in the system. The criticality condition of the system is determined from information generated in the encounters of the neutrons with the materials of the system. This information is related to the probabilities of a neutron being scattered, being absorbed without causing fission, or being absorbed causing fission in a given encounter. In effect, the method mimics the behavior of real neutrons in a real reacting system.

Also of great importance to the accuracy of KENO in applications is its lack of geometrical limitations. That is, geometrical approximations do not have to be made to fit the system of interest to the program. (However, there may be limitations due to the fast memory capacity of the EDPM equipment being used.) This capability removes the necessity for some "conservative approximations" which must be made to use alternative calculational programs of otherwise great merit; for example, ANISN. With adequately validated cross sections, KENO results can be and are being used as equivalents to experimental results.^(12,13)

Neutron Interaction Cross Sections - Neutron interaction cross sections are obtained from physics experiments and so, like the results of all other physical measurements, have associated experimental uncertainties. Furthermore, without going into detail, it should be noted that different workers in the field treat the fundamental cross-section information using different theories. Consequently, numerous sets of cross sections have been developed which when used to solve the same problems do not give exactly the same answer. As yet, no one has proven that a compilation of cross sections exists that does not limit the inherent accuracy of the KENO program, although eventually the ENDF/B cross-section compilation⁽¹⁴⁾ may do so. Attempts have been initiated to use this compilation in KENO; although, as will be taken up next, currently available EDPM equipment capabilities may limit applications.

The neutron energy range over which a cross-section compilation or set must describe neutron interactions with materials for criticality safety analysis (and reactor analysis) is about nine orders of magnitude in extent; that is, from about 0.025 electron Volt (thermal) to about 10^7 electron Volts. The amount of ENDF/B information which must be stored in the fast memory of a computer for U-235 and U-238 alone comprises better than 90 percent of the available daytime capacity of the IBM 360 Model 65 (360/65) computer at the Oak Ridge Computing Technology Center, almost 50 percent of the capacity of the 360/75 computer, and more than 10 percent of the capacity of the 360/91 computer. The latter two machines are at the Oak Ridge National Laboratory. Since KENO itself takes up a reasonable amount of fast memory capacity and since there are usually other materials that must be considered in a problem, by

using ENDF/B cross sections: (1) nothing at all can be run on the 360/65, (2) only very limited problems can be run on the 360/75, and (3) many problems are too large for the 360/91. Full direct utilization of the ENDF/B data in solving problems awaits the next generation of EDPM equipment both for reasons of data storage and for reasons of processing time.

In regard to the latter, the use of the amount of information available in a cross-section compilation such as ENDF/B consumes appreciable computer time because so much information has to be sifted to find that part that is applicable to a single neutron-material encounter. Such compilations have become available only relatively recently; and, for the reasons just enumerated, are applied directly to few problems. In the past, present, and certainly far into the future, cross-section sets which are averages over large energy ranges find the most application. In fact, the cross-section set which has proved of most value in Y-12 applications is the Hansen-Roach 16-energy-group set,⁽¹⁵⁾ which breaks the nine-order-of-magnitude energy range of interest into only 16 bands or groups. For U-235 and U-238, this set uses only about 0.2 percent of the computer fast memory capacity required by the ENDF/B data, thus leaving more memory capacity for program and other input data storage.

Validation Methods - Because the averaging that was done in developing the Hansen-Roach set may lead to erroneous results when used in certain problems, validation of these cross sections has been and continues to be pursued. The validation procedure consists of comparing the results of computer-calculated criticality conditions of critical systems with experimentally measured ones. For KENO, such validation has been and continues to be done primarily by the Y-12 Criticality Safety Group^(16 - 18) and the Critical Experiment Facility^(18,19) with the assistance of the Scientific Applications Department of the Oak Ridge Computing Technology Center.^(20,21) The same cross-section set is used with the ANISN program, and Stratton of LASL has done a great deal of the validation of the set as used with ANISN and related programs.⁽²²⁾

It has been demonstrated, however, by Stratton and others,⁽²³⁾ that the cross sections are inadequate for most systems containing low to low-to-intermediate enriched uranium; and, under special circumstances, even for some systems containing such a common material as iron.⁽²⁴⁾ These inadequacies have come to light in carrying out the validation procedures, and there remains considerable work yet to be done in this area.

Status - On the whole, the development of KENO represents a major step forward in the field of criticality safety analysis. Many facilities in the country are adopting it not only for that use; but, also, there is promise for its use in power reactor analyses. The validation procedure has delineated the limitations of the Hansen-Roach cross-section set so that much trust can be put in the results of calculations on systems which have not been investigated experimentally. For criticality safety purposes at Y-12, any system which has a calculated k_{eff} greater than 0.97 ($k_{eff} = 1.00$ is just

critical), including two statistical standard deviations, is assumed to be critical. This criterion, which was established more than two years ago, (16) needs reexamination in the light of certain improvements that have subsequently been made in the technique. However, it is not expected that the number can be increased as much as one percent without revising the cross sections. It is in such revisions that the ENDF/B data may find their greatest application; that is, they may be "collapsed" or averaged into one or more new group structures. For example, it is fairly certain that more than the 16 energy groups of the Hansen-Roach set are required to adequately describe the cross-section structure of U-238 or iron for many compositions containing them.

The ANISN Program

The ANISN program, which has already been referred to frequently, finds a number of uses in the analysis of storage and shipping problems. Although this program can be used not only to find the criticality condition of a fixed dimension system but also to vary the dimensions of the system being calculated to meet a given criticality condition, it has one significant limitation. It is limited to individual systems that can be represented by spheres, circular cylinders of infinite length, or flat slabs of infinite lateral extent. As will be detailed in the next section, however, it has found some very important applications in Y-12 Plant problems, along with its immediate predecessors, the DTF and DSN programs.

This program solves the basic neutronics equation using the S_n method developed by Carlson. (25) In this method, the average neutron behavior is treated in terms of continuous quantities such as neutron currents. A mathematical description of this program is beyond the scope of this report but can be found in the work of Carlson.

ANISN is, by its nature, restricted to using group structure cross sections. It is by no means limited to the Hansen-Roach set and so will also be able to benefit from "collapsing" the ENDF/B data.

APPLICATIONS OF KENO AND ANISN

Storage Problems

General - Technical and economic interests have generated the need for solutions of storage problems that exceed the capabilities of many techniques, including the direct use of experimental data. Such problems often involve storage array patterns for which linear, plane, or cubic-shape approximations give unacceptable answers. They may also involve interactions among more arrays than the techniques can handle. KENO is extremely well adapted to the solution of such problems, three of which are discussed in the sections that follow.

Large, Vertical Array Storage - In most areas of the Y-12 Plant, floor space is at a premium. Storage arrays for fissile materials in many operating areas take up floor

space that might otherwise be better utilized. To release this space, vertical storage along walls has been proposed. Calculations using KENO have been made to show conditions under which over 1,000 storage locations could be arranged along the walls of rooms at spacings typical of the usual, far smaller arrays. In these studies, it was also shown that the reflective effect of even large numbers of personnel on these arrays can be essentially discounted. Similar realistic analyses can be made using KENO that are impossible with other types of techniques.

Vault Storage - Storage in rooms in which a majority of the useful space is taken up by an array or arrays is termed "vault storage". KENO has been used to give realistic analyses of typical vault storage patterns including the effects of aisles between double rows of storage locations and the moderating effect of personnel in vaults. These studies have indicated that the effect of the aisles on the reactivity of the array is very pronounced. In some cases the effect is as great as if the fissile units being stored were spaced uniformly in the volume of the vault rather than in closer spacing in rows with aisles between rows. Also, it was shown that the moderating effect of even large numbers of personnel in the vault may be essentially discounted.

The results of these studies demonstrated that increases in vault storage capacities may be made and that storage patterns can often be altered to increase the operational efficiency.

Storage in the Principal Oralloy Preparation Area - The largest project undertaken to date is an analysis of the interaction of all fissile material in the whole of the principal oralloy preparation area of the Y-12 Plant, considered as a single reacting system. Conservative approximations were made in regard to both the amount of oralloy and the amounts and types of moderating and reflecting materials present in the area. The results of this study, using KENO, showed that for any foreseeable storage in this area, the safety factor would be considerably greater than the customarily acceptable factor of two.

Shipping Problems

General - A situation similar to that which exists for the solution of storage problems exists for shipping problems. In addition, recent AEC regulations⁽²⁷⁾ have requirements which can never be the subject of practical experimentation because huge numbers of containers and amounts of fissile material would be needed.⁽⁶⁾ Both ANISN and KENO may be used in the solution of shipping problems; the former, practically, only for Fissile Class I shipments. (The fissile materials in different Fissile Class I containers do not interact significantly.)

Weapons Components Shipping - Both ANISN and KENO have been used to investigate the criticality safety of the shipment of weapons components, devices, and component parts. On the basis of such investigations, Y-12 recommended to the AEC-ORO that the existing limits on railcar shipments could be revised drastically upward. This recommendation is under study by the AEC-ORO.

The designs of shipping containers to be used in all new programs are investigated for criticality safety using these methods. Also, where containers designed to satisfy earlier regulations failed to meet the new regulations, they have been modified; or, if necessary, replaced with a new type.

Other Shipments - Analyses using ANISN and KENO have been made for the use of all other shipping containers utilized since the new AEC regulations became effective. Some of the fissile materials shipped in these containers are: (1) Rover fuel elements, (2) New Brunswick Laboratory salvage, (3) the Aberdeen reactor, and (4) uranium compounds such as oxides.

CONCLUSIONS

Use of the existing calculational program, ANISN, and the development and use of the new program, KENO, have brought significant direct benefits to the Y-12 Plant in analyzing the criticality safety of storing and shipping fissile materials. These benefits are in addition to those obtained from the application of these programs to the criticality safety analysis of processing and manufacturing procedures in the Plant. Indirect benefits to the Plant come from the application of these programs to the extension of experimental data needed for the development of general, non-EDPM methods of analysis.

The realism possible in treating problems using the KENO program has allowed the evaluation of a number of effects such as moderation by people and reflection by machines and machining setups that have heretofore been inadequately evaluated. These evaluations have opened new avenues of approach to problems in which the amount of conservatism added merely to compensate for ignorance (not because no one wanted to know but rather because it was too hard to find out) can be sharply reduced.

Further development in calculational capability such as the use of ENDF/B cross sections and additional geometrical mockup options in KENO will result in further increases in analysis capabilities and so must be pursued. A necessary part of this development is the continuing procedure of validation of the calculational techniques using existing and new critical experiment data. Only by such a validation procedure can the necessary confidence in its application be maintained at its present level, or increased.

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