Abstract
Thursday, January 13, 2005

Nuclear Science and Technology Division (94)

History of the Oak Ridge Critical Experiments Program

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Submitted to
The American Nuclear Society 2005 Annual Meeting on
The Next 50 Years: Creating Opportunities,
June 5–9, 2005,
San Diego, CA

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[†] Managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 with the U.S. Department of Energy.

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INTRODUCTION

This is a summary of an overview presentation on the critical experiments program conducted at the three Oak Ridge sites (X-10, K-25, and Y-12) during the Heritage Period between 1943 and 1973. Much of the subject matter was included in discussions by six of the experimentalists and other participants in the three-day (May 21–23, 2001) Heritage [1] recording sessions. The broad scope of the program is addressed in this overview through a brief description of the four areas supported by the program: (1) nuclear material production, (2) basic physics, (3) reactor design, and, (4) fissionable material transportation and storage. Additional topics addressed include the development of experimental equipment and procedures, analytical tools, safety guidance documentation, and criticality safety standards.

CHRONOLOGY OF SITE OPERATIONS

Early Activities at X-10

The first nuclear criticality on the Oak Ridge reservation occurred early in the morning of November 4, 1943, when the Graphite Reactor at the X-10 site first achieved criticality. The Graphite Reactor "startup crew" included Louis Slotin and Bernard Feld, two of the "pioneers" of critical assembly measurements from the Metallurgical Laboratory of the University of Chicago. While at X-10, they conducted source-driven multiplication measurements on large assemblies of uranium metal, as well as on thermal-neutron systems of metal-rod water lattices. These were most likely the first subcritical measurements performed in Oak Ridge.

Regarding material production, in the summer of 1945, Art Snell and his group performed critical and subcritical measurements on assemblies that simulated uranyl fluoride enriched to 24%. Six of the nine assemblies were critical. Hugh Paxton, the leader of the Los Alamos Critical Experiments Facility for many years, observed these measurements at the X-10 site. Edward Teller advised on techniques for heterogeneity corrections in the analysis of these assemblies. Additionally, fission-source-driven multiplication measurements were performed on a 300-lb product drum. The water-reflected drum contained uranium hexafluoride at U-235 isotopic concentrations of 1.1 and 0.536%. The product-drum multiplication measurements supplemented theoretical estimates made by Edward Teller and others.

Activities in the F05 Facility at K-25, 1945 to 1950

Continued interest in the criticality safety issues associated with the gaseous diffusion process led to the establishment of the criticality safety research group at K-25 under the leadership of Dixon Callihan. Beginning in late 1945, Callihan organized an effort to investigate the safe mass and volume limits of uranium-fluorine compounds as a function of enrichment and moderation. In early 1946 he arranged to transfer material to Los Alamos, where Louis Slotin and Bernard Feld had been conducting critical experiments at the Omega Site. In March and April, Louis Slotin instructed Dixon Callihan, Clifford Beck, and Raymond Murray in the performance of critical experiments with the hand-stacking technique. They returned to Oak Ridge only a few weeks before Louis Slotin's fatal hand-stacking accident on May 21, 1946. Therefore, they designed the critical experiment facility in Building F05 at K-25 to provide remote split-table assembly with controls located in a shielded area. A number of dry-moderated $U(30)O_2F_2$ critical configurations were measured, followed by an extensive series of uranium solution measurements. These were reported in the series of K-25 documents: *Critical Mass Studies, Parts I-V.*

Activities in the Oak Ridge Critical Experiments Facility (ORCEF—Building 9213), 1950 to 1973

Over 22,000 critical configurations were measured at Oak Ridge, with the vast majority being performed in the three cells of Building 9213. ORCEF was operated as part of Oak Ridge National Laboratory from 1950 until 1968, and then operated as part of the Y-12 Plant until 1973.

In addition to those already discussed, the overall list of "hands-on" experimentalists participating at some stage in the measurements programs included G. Booth, D. F. Cronin, C. Cross, E. C. Crume, J. Ellis, J. K. Fox, L. W. Gilley, R. Gwin, E. B. Johnson, W. E. Kinney, R. L. Macklin, D. W. Magnuson, R. Malenfant, J. H. Marable, J. T. Mihalczo, J. W. Morfitt, S. J. Raffety, R. K. Reedy, Jr., E. R. Rohrer, C. L. Schuske, J. R. Taylor, J. T. Thomas, G. Tuck, W. C. Tunnell, D. V. P. Williams, and E. L. Zimmerman. Many other

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experimentalists from military and government contractor organizations participated in the planning and performance of experiments at ORCEF. Administrative and technical support was provided by a number of specialists including C. A. Burchsted, F. Faust, R. B. Gallaher, G. A. Garrett, H. F. Henry, C. M. Hopper, R. E. Hoskins, D. C. Irving, W. Jordan, A. J. Mallett, J. D. McLendon, W. T. Mee, C. E. Newlon, A. M. Perry, G. E. Whitesides, M. Williams, and certainly many others.

EXPERIMENTAL PROGRAMS BY APPLICATION AREA

Nuclear Material Production

In addition to the dry-moderated and solution experiments already mentioned, there were the 2 and 3% enriched "green block" experiments, arrays of solution bottles in conjunction with reflecting walls, and a number of prototypic equipment vessels with demonstration of safe shape and/or volume for projected operations. These included both U-235- and U-233-fueled systems.

Basic Physics

Experimental observation of the physics of array criticality was developed at ORCEF. This effort included the "Tinker Toy" measurements of three-dimensional arrays of metal and solution units. These measurements led to the development of the $N(B_N)^2$ method for array analyses as well as the step-by-step development of the geometry and neutron-tracking schemes in the KENO Monte Carlo criticality program. Additionally, a two-dimensional array of metal units was utilized in the verification of two-dimensional discrete-ordinates transport codes. The geometric-grotesque configuration challenged geometry modeling capabilities, and the U-233 η experiments demonstrated the feasibility of U-233 light-water conversion reactors.

Reactor Design

Fuel assemblies designed for power and research reactor application were neutronically demonstrated in critical experiments at ORCEF. These designs included the Experimental Beryllium-Oxide Reactor (EBOR); the Army Packaged Power Reactor (APPR); the BONUS Integral Nuclear Superheat Reactor; and many others, some of which included designs for space and military aircraft application. Two sets of experiments were conducted first to establish the design of the High Flux Isotope Reactor (HFIR) and then to verify the design of the fuel assemblies.

Fissionable Material Transportation and Storage

In addition to the critical arrays discussed above, a number of experimental programs at ORCEF addressed the needs for safe storage and transportation package loadings and interaction–isolation. Typical of these were the measurements performed with 30- and 60-cm-long U(4.89) metal rods. These covered a wide variety of parametric variations including rod diameter, lattice type and pitch, internal lattice voids, internal fixed and soluble absorbers, and various types of reflectors.

ADDITIONAL ORCEF STAFF DEVELOPMENTS

Experimental Equipment and Techniques

Already noted is the early introduction of remote assembly on a split table. The mechanical design of the ORCEF split tables went through several generations and reached a high level of precision, safety, and reliability. Several techniques for subcritical measurements were developed and utilized. The most notable is the Cf-252 noise technique of John Mihalczo.

Safety Guidance Documentation and Criticality Safety Standards

The ORCEF leadership and staff members played pioneer roles in both of these areas. They participated in the development of the basic criticality safety guidance documentation. They served on standards writing groups and on ANS-8 and N-16 in both technical and administrative roles.

CONCLUSION

The Oak Ridge Critical Experiments Program made substantial contributions to the understanding of criticality experimental data, as well as to the performance of safe and efficient criticality safety practice.

REFERENCES

1. ORCEF Staff Members, *Heritage 2001—The Oak Ridge Critical Experiments Program*, Oak Ridge National Laboratory (2001).