ORNL/TM-10649

ornl

OAK RIDGE
NATIONAL
LABORATORY

MARTIN MARIETTA

One-Dimensional S_N Calculations to Evaluate the Shielding for an Alpha-Particle Charge Exchange Neutral Analyzer

R. T. Santoro
W. K. Dagenhart
J. M. Barnes

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A02 Microfiche A01

ORNL/TM-10649

Engineering Physics and Mathematics Division

ONE-DIMENSIONAL S_N CALCULATIONS TO EVALUATE THE SHIELDING FOR AN ALPHA-PARTICLE CHARGE EXCHANGE NEUTRAL ANALYZER

R. T. Santoro, W. K. Dagenhart,* and J. M. Barnes**

*Fusion Energy Division
**Computing and Telecommunications Division

DATE PUBLISHED — January 1988

Prepared by
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

CONTENTS

ABSTRACT

One-dimensional discrete ordinates calculations have been carried out to estimate the effectiveness of both concrete and stainless-steel plus borated water shadow shields in reducing the neutron and gamma-ray background levels at an alpha-particle charge exchange neutral analyzer. The system is proposed for studying the alpha particle and plasma characteristics of fusion machines with ignited plasmas such as the CIT. A stainless-steel-borated water shield was determined to be effective in reducing background counting rates.

1. INTRODUCTION

A diagnostic neutral beam line, in combination with a charge exchange neutral analyzer, has been proposed to study the space, time, and momentum distributions of alpha-particles produced in a D-T burning fusion reactor.[1–7] These data are necessary for understanding the plasma behavior and characteristics of early fusion burning devices such as the Compact Ignition Torus (CIT) and for establishing the plasma data base for designing fusion reactors beyond the CIT. This memorandum summarizes the results of one-dimensional discrete ordinates calculations that have been carried out to estimate the composition and thickness of shielding required to reach acceptable neutron and gamma-ray induced background counting rate in the vicinity of an alpha particle charge exchange neutral detector located outside of the reactor shield. The calculations were performed as part of a feasibility study for an alpha particle diagnostic neutral beam line system which would be used in measuring the fusion reactor plasma characteristics of fusion machines with ignited D-T burning plasmas.

2. DETAILS OF THE CALCULATIONS

2.1. REACTOR AND DIAGNOSTIC SYSTEM

The fusion reactor configuration that was considered for this analysis is that of the CIT and shown in Figure 1. The plasma has an elliptic cross-section with semiaxis dimensions of 55 and 110 cm and a major radius of 150 cm corresponding to a plasma volume of 1.79×10^7 cm. The 14-MeV neutron production at full power operation is 1.3×10^{20} n/s.[5] The reactor vacuum vessel and the toroidal and poloidal magnetic field coils are located inside of a concrete shield structure having a wall thickness of 180 cm. The plasma characteristics are determined by diagnostic instrumentation located outside of this shield that views the plasma through a 10-cm-diameter duct in the reactor shield. The viewed volume of the plasma is 8.34×10^3 cm assuming that a plasma length of 110 cm is seen by the diagnostic instrumentation.

Figure 2 shows the orientation of the alpha-particle diagnostic analyzer with respect to the 10-cm-diameter duct in the shield. The detector is not in direct line-of-sight with the viewed volume, being separated by at least two shielded 90° bends of the beam so the contribution of the uncollided neutron flux to the background is minimized.[8] If it is also assumed that the plasma neutrons are partially shielded by the toroidal coils, then the neutron attenuation due to the coils and the concrete shield structure is of the order of seven orders of magnitude. (Concrete reduces the 14-MeV neutron flux by an order of magnitude per foot and a factor of ten is attributed to the presence of the coils.) The bending magnets also contribute to a further reduction of the neutron intensity.

Since the neutron production rate in the CIT is large, additional shielding will be required to reduce the background counting rate at the diagnostic instrumentation. For this study, a 100-cm-thick shadow shield was located immediately in front of the diagnostic system and at a distance of 640 cm from the penetration in the reactor shield. Concrete and stainless-steel plus borated water ($SS+H_2OB$) shield materials were studied for reducing the neutron and gamma-ray count rates. We assume that shielding will be added to the two 90° bend transport systems to prevent secondary radiation from reaching the alpha particle detector.

2.2. CALCULATIONAL MODEL

The one-dimensional discrete ordinates code, ANISN,[9] was used to calculate the neutron and gamma-ray flux behind the shadow shield. The reactor, local shielding, and the shadow shield were modeled in cylindrical geometry with symmetry about the plasma axis. The calculational model including the dimensions and composition of the various components is summarized in Table 1. The radiation transport was carried out using a 35-neutron-21-gamma-ray energy group cross-section library[10] using a P_3 Lengendre expansion to estimate the angular dependence of the scattering data and an S_8 angular quadrature.

In these calculations, the plasma is represented with circular cross section with radius $r = \sqrt{ab}$, where a and b are the semiaxes of the elliptic plasma. The plasma volume was held constant. In cylindrical geometry, ANISN yields the neutron and gamma-ray flux per neutron per unit length of the plasma. The flux data was normalized using $1.3 \times 10^{20}/(2\pi R_m) = 1.37 \times 10^{17}$ n/cm $\cdot$ s, where R_m is the major radius of the plasma. Since it is not possible to account for the finite dimension of the toroidal coils or the penetration in the shield in a one-dimensional model, these were not included in the calculation. Two- or three-dimensional transport analyses are necessary to account for the coils and neutron radiation streaming through the duct.

Table 1

Dimensions and Compositions of the
Reactor-Shield Calculational Model

Zone	Description	Outer Radius (cm)	Material
1	Plasma	77.0	Vacuum
2	Vacuum Vessel	78.0	Stainless Steel 316
3	Void	228.0	Vacuum
4	Shield	408.0	Ordinary Concrete
5	Void	1048.0	Vacuum
6	Shadow Shield	1148.0	Ordinary Concrete or Stainless-Steel plus Borated Water (a)

(a) 65% Stainless-Steel, 35% Borated Water (6% Boron Concentration)

3. DISCUSSION OF RESULTS

The calculated neutron and gamma-ray fluxes as a function of energy immediately behind the shadow shield are shown in Figures 3 and 4, respectively. Compared in Figure 3 are the neutron spectra when concrete and SS+H_2OB are used as the shadow shield material. The SS+H_2OB shield is clearly more effective in reducing the neutron background. The neutron flux is of the order of 10 $n/cm^2 \cdot s$ or less over the neutron energy range from 10^{-7} to 14 MeV and several orders of magnitude lower at all energies than the neutron flux behind the concrete shadow shield. The integrated neutron flux is 14 $n/cm^2 \cdot s$ compared to 25000 for concrete, or nominally 1800 times more effective in lowering the neutron background.

The SS+H_2OB is equally effective in reducing the gamma-ray flux as shown in Figure 4. However, the magnitude of the photon flux is greater than the neutron flux behind both the concrete and SS+H_2OB shadow shields. The integrated gamma-ray flux for the steel-water assembly is 1.1×10^2 $\gamma/cm^2 \cdot s$ compared to 2.1×10^6 $\gamma/cm^2 \cdot s$ for the concrete shield. The steel-water is, therefore, four orders of magnitude more effective in reducing the gamma-ray background albeit the gamma count rate is two orders of magnitude greater than the neutron count rate. However, at a nominal 125 particles/$cm^2 \cdot s$, the count rate should be within acceptable levels, ignoring contributions from radiation streaming through duct in the reactor shield for identifying the charged particles emitted from the plasma.

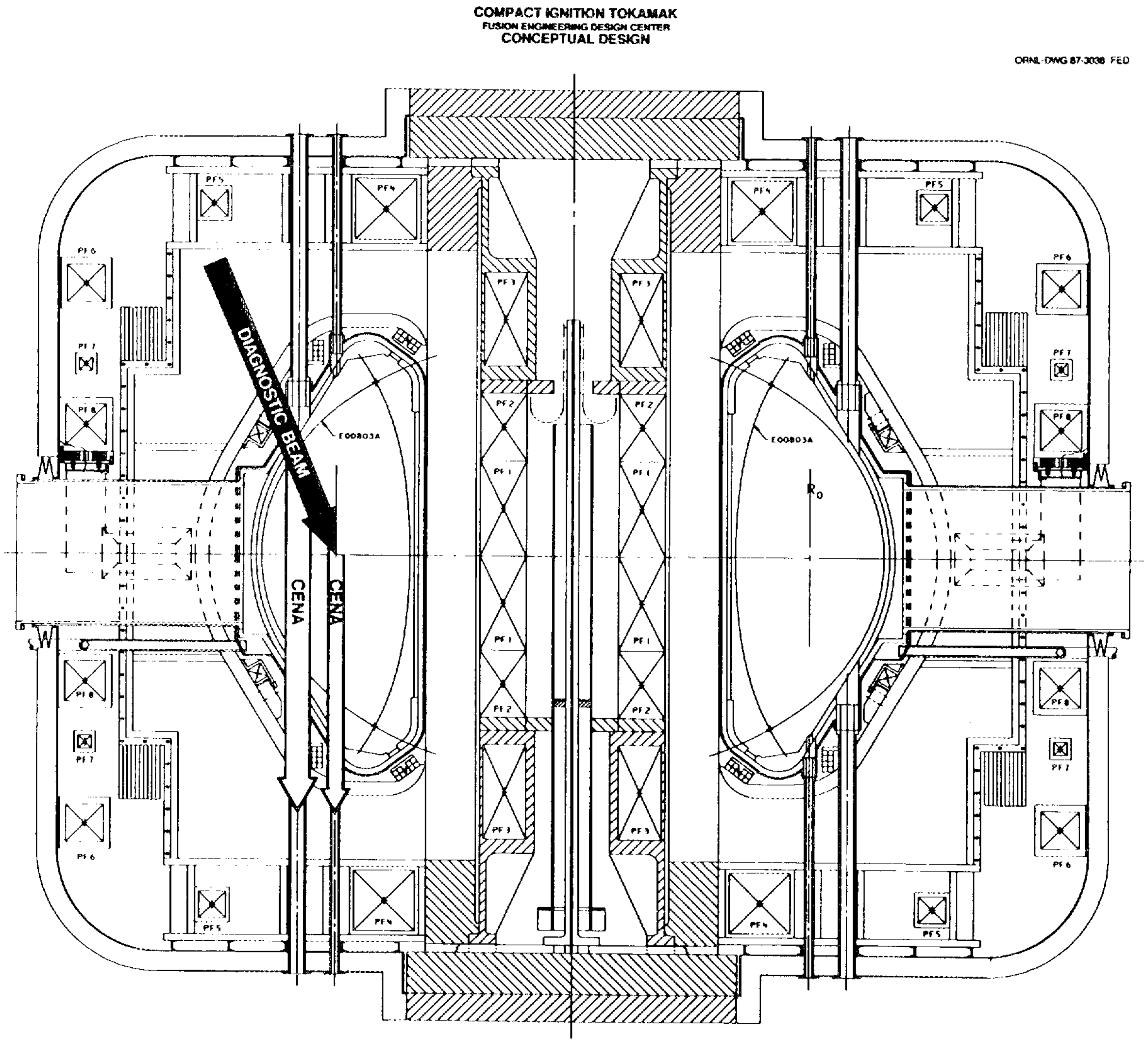

Figure 1. Compact Ignition Torus Reference Design

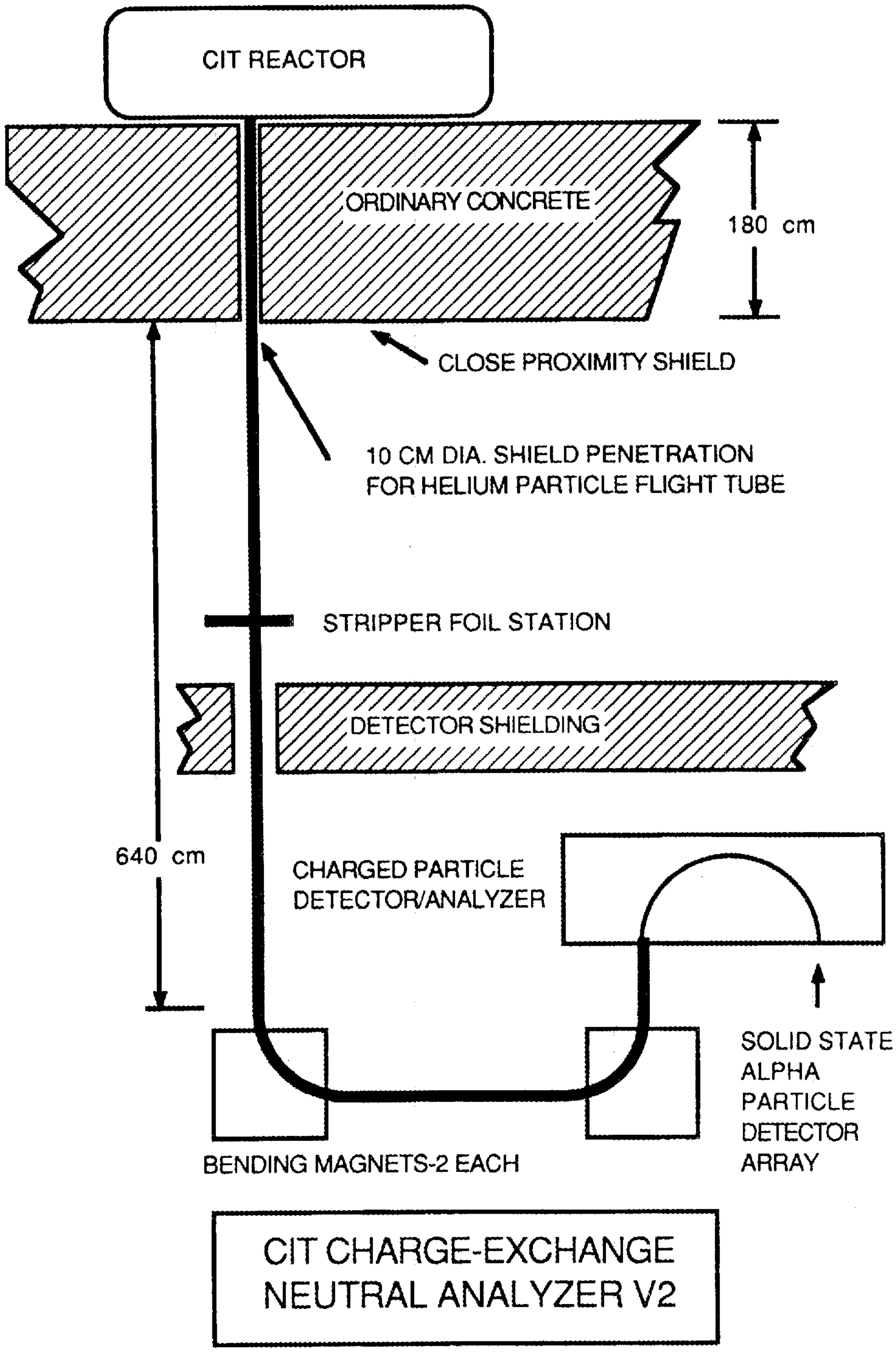

Figure 2. Schematic Diagram of the CIT Charge-Exchange Neutral Analyzer

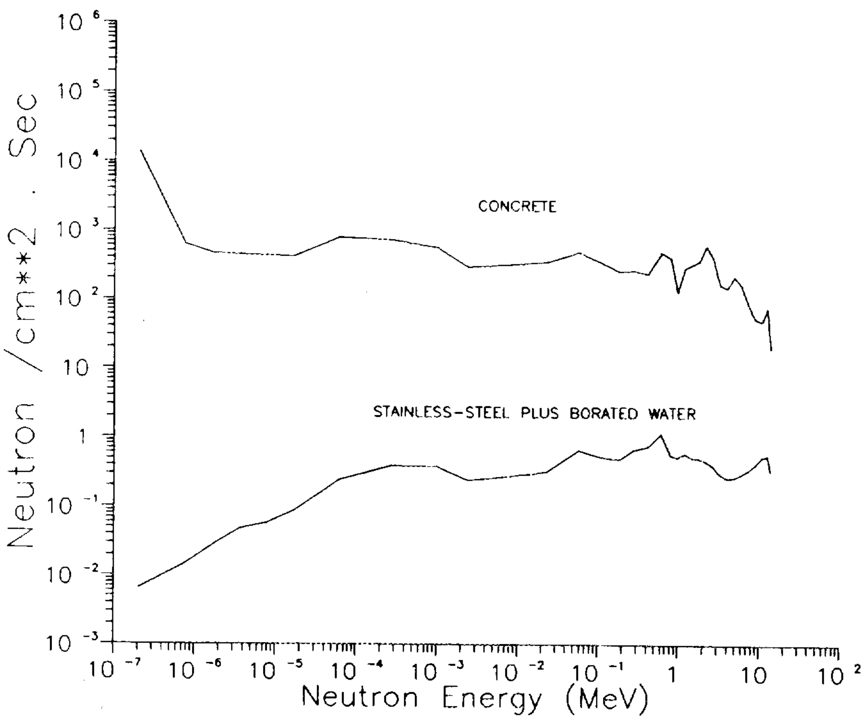

Figure 3. Neutron Flux vs. Energy Behind Concrete and Stainless Steel Plus Borated Water Shadow Shields

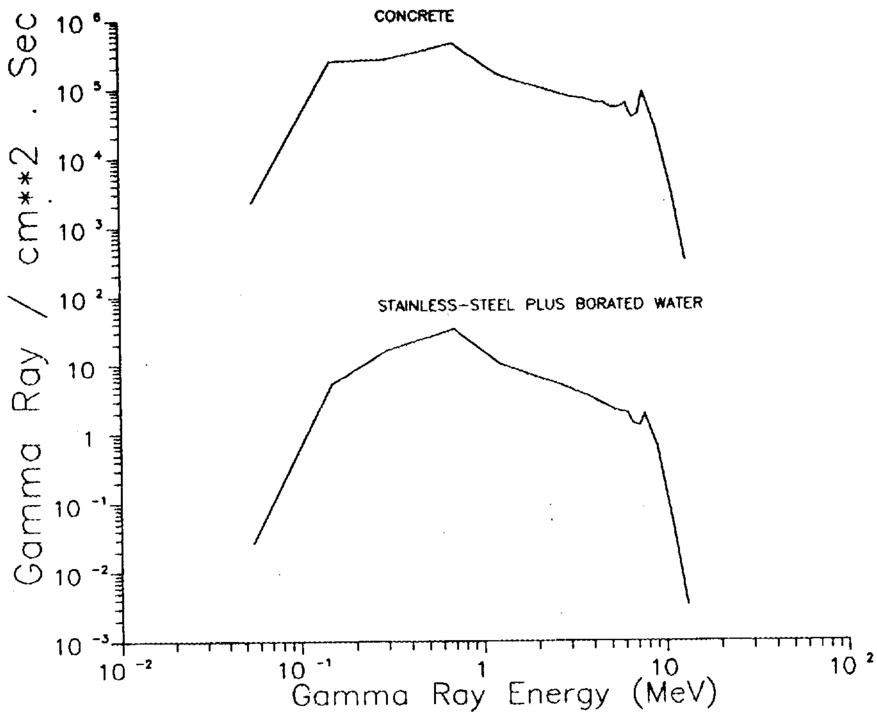

Figure 4. Gamma Ray Flux vs. Gamma-Ray Energy Behind Concrete and Stainless Steel Plus Borated Water Shadow Shields

REFERENCES

1. D. E. Post, D. R. Mikkelsen, R. A. Hulse, L. D. Stewart, and J. C. Weisheit, "Techniques for Measuring the Alpha-Particle Distribution in Magnetically Confined Plasmas," *Journal of Fusion Energy*, Vol. 1, No. 2, 1981.

2. Larry R. Grisham, Douglass E. Post, and David R. Mikkelsen, "Multi-MeV Li^0 Beam as a Diagnostic for Fast Confined Alpha Particles," *Nuclear Technology/Fusion*, Vol. 3, p. 121, January 1983.

3. W. K. Dagenhart, W. L. Stirling, C. C. Tsai, and J. H. Whealton, "An Alpha Particle Diagnostic Beam Line System to Generate an Intense Li^0 Beam with an ORNL SITEX Source," *Fusion Technology*, Vol. 8, p. 387, July 1985.

4. W. K. Dagenhart, M. J. Gouge, W. L. Stirling, and J. H. Whealton, "Neutral Beam Fast Alpha Diagnostic for CIT," *Presentations From the Workshop on Alpha-Particle Diagnostics on CIT*, AA-870710-PPL-06,PPPL, 3-5 June 1987.

5. W. K. Dagenhart, W. L. Stirling, M. J. Gouge, R. T. Santoro, C. C. Tsai, and J. H. Whealton, "A Light Mass Alpha Particle Diagnostic Neutral Beam Line," *Bull. of the American Physical Society*, Vol. 32, Number 9, October 1987.

6. J. A. Schmidt, *Compact Ignition Tokamak Conceptual Design Report*, PPPL, June 6, 1986.

7. N. A. Uckan, FEDAIM 1986, private communication.

8. R. T. Santoro, J. M. Barnes, R. G. Alsmiller, Jr., and J. D. Drischler, "Monte Carlo and Discrete Ordinates Calculations for 14 MeV Neutrons Streaming Through a Stainless Steel Duct: Comparisons with Experiment," *Nuclear Instruments and Methods in Physics Research*, A250 (1986) pp. 557-564.

9. W. W. Engle, Jr., *ANISN: A One-Dimensional Discrete Ordinates Transport Code with Anisotropic Scattering*, Oak Ridge National Laboratory Report, K-1693 (1967).

10. R. T. Santoro, R. W. Roussin, and J. M. Barnes, *FLUNG: Coupled 35-Group Neutron and 21-Group Gamma Ray, P_3 Cross Sections for Fusion Applications*, Oak Ridge National Laboratory Report, ORNL/TM-7828 (1981).

INTERNAL DISTRIBUTION

1. M. A. Akerman
2. R. G. Alsmiller, Jr.
3–7. J. M. Barnes
8. W. R. Becraft
9. D. G. Cacuci
10–14. W. K. Dagenhart
15. T. A. Gabriel
16. M. J. Gouge
17. H. H. Haselton
18. J. K. Ingersoll
19. F. C. Maienschein
20. O. B. Morgan
21. V. Protopopescu
22. M. W. Rosenthal
23–27. R. T. Santoro
28. M. S. Smith
29. W. L. Stirling
30. C. C. Tsai
31. N. A. Uckan
32. J. H. Whealton
33. A. Zucker
34. J. J. Dorning (Consultant)
35. G. H. Golub (Consultant)
36. R. M. Haralick (Consultant)
37. D. Steiner (Consultant)
38. EPMD Reports Office
39–40. Laboratory Records Department
41. Laboratory Records, ORNL-RC
42. Document Reference Section
43. Central Research Library
44. ORNL Patent Office

EXTERNAL DISTRIBUTION

45. Dr. David H. Crandall, Chief, ER542 G215 GTN, Experimental Plasma Research Branch, Division of Applied Plasma Physics, Office of Fusion Energy, Office of Energy Research, U.S. Department of Energy, Washington, D.C. 20545
46. L. R. Grisham, Princeton Plasma Physics Laboratory, Princeton, New Jersey 08540
47. S. S. Medley, Princeton Plasma Physics Laboratory, Princeton, New Jersey 08540
48. D. Mikkelsen, Princeton Plasma Physics Laboratory, Princeton, New Jersey 08540
49. D. E. Post, Princeton Plasma Physics Laboratory, Princeton, New Jersey 08540
50. K. M. Young, Princeton Plasma Physics Laboratory, Princeton, New Jersey 08540
51. S. J. Zweben, Princeton Plasma Physics Laboratory, Princeton, New Jersey 08540

52. Office of Assistant Manager for Energy Research and Development, Department of Energy, Oak Ridge Operations Office, P.O. Box E, Oak Ridge, Tennessee 37831

53–82. Technical Information Center