THERMOELASTIC ANALYSIS OF WASTE-CONTAINER SLEEVE

Technical Memorandum Report RSI-0008

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January 18, 1974

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**UNION
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OFFICE OF WASTE ISOLATION
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THERMOELASTIC ANALYSIS OF WASTE-CONTAINER SLEEVE

TECHNICAL MEMORANDUM REPORT [RSI-0008]

Submitted To

Oak Ridge National Laboratory
Oak Ridge, Tennessee
operated by
Union Carbide Corporation
for the
U.S. Atomic Energy Commission

By

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January 18, 1974

MASTER

TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES.	i
LIST OF TABLES	ii
1. INTRODUCTORY REMARKS	1
2. PRESENTATION AND DISCUSSION OF RESULTS	2
APPENDIX A: Comparison of RSI/TRANCO Temperature Fields with ORNL Results for the Lyons, Kansas Site. .	A-1
APPENDIX B: Transient Temperature Field for the Room and Pillar configuration at the New Mexico Pilot-Plant Site.	B-1
APPENDIX C: Thermoelastic Stress Distribution in the Near-Field Vicinity of the Sleeve-Waste Container at the New Mexico Pilot-Plant Site. .	C-1
REFERENCES	

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Schematic representation of various limiting boundary conditions of the sleeve-salt interface and the corresponding (qualitative) radial pressure distributions due to thermal and lithostatic loading.	5
A.1.	Schematic representation of the SALT-5/T finite element model used in RSI/TRANCO.	A-2
A.2.	Comparison of temperature distributions generated by RSI/TRANCO and those obtained by ORNL for the Lyons, Kansas site.	A-5
B.1.	Finite element grid for the room and pillar configuration at the New Mexico pilot-plant site.	B-2
B.2.	Time dependent temperature rises at various locations in the finite element r-z models for the New Mexico pilot-plant site.	B-4
B.3.	Temperature rise along the sleeve-salt interface at various times.	B-6
C.1.	Radial pressure profile along the sleeve-salt interface due to lithostatic loading.	C-3
C.2.	Radial pressure profile along the sleeve-salt interface due to 5 years of heating [Top of model restricted to zero vertical displacement].	C-5
C.3.	Radial pressure profile along the sleeve-salt interface due to thermal loading after 5 years of heating [Top of model subjected to overburden load].	C-6
C.4.	Radial stress distribution at a depth of 2,013 feet in salt after 5 years of heating [Stress due to temperature field only].	C-7
C.5.	Stress state at the sleeve-salt interface as a function of heating time at a depth of 2,013 feet [Solid steel cylinder in drillhole].	C-9

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Tabulation of radial pressure at the sleeve-salt interface for different model conditions after 5 years of heating with a 5 KW thermal source.	6
A-1	Summary of thermal conductivities utilized in the SALT-5/T model.	A-3

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TECHNICAL MEMORANDUM REPORT [RSI-0008]

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SUBJECT: Thermoelastic Analysis of Waste-Container Sleeve [Union Carbide Corporation, Nuclear Division Subcontract No. 3706; RSI/001000/FY74].

1. INTRODUCTORY REMARKS

The analysis of the radial pressure distribution on the waste-container sleeve requires consideration of the composite elastic/plastic/creep behavior of the salt and the corresponding interaction with the steel sleeve during heat generation by the waste. As a prelude to the more complete analysis, the contents of this report are restricted specifically to the thermoelastic aspects of the analysis, and include:

- (1) a quantitative comparison between the temperature fields generated by the RSI/TRANCO finite-element computer code and results obtained by ORNL personnel for the Lyons, Kansas site (Appendix A);
- (2) a determination of the transient temperature field for the room and pillar configuration that is proposed for the New Mexico pilot-plant site (Appendix B);

- (3) an analysis of the thermoelastic stress distribution in the near-field vicinity of the sleeve-waste container at the New Mexico pilot-plant site (Appendix C).

In all instances, use is made of two-dimensional finite-element models in r-z geometry. The mechanical, physical, and thermal properties of the various components of the finite-element models have been taken from previous reports by ORNL and RSI personnel (see ORNL-4789, RSI-0002, and RSI-0005). With regard to the New Mexico pilot-plant site, the waste is assumed to have an initial zero temperature and initial thermal power output of 5 KW with a decay constant of 0.023105 per unit time; the dimensions of the room and pillar configuration were furnished by ORNL personnel (ref.: RSI/ORNL/USAEC meeting at the University of Utah on October 10, 1973).

2. PRESENTATION AND DISCUSSION OF RESULTS

As indicated in Appendix A, the temperature fields computed with the RSI/TRANCO finite-element code, for limiting values of the thermal conductivity of salt, effectively encompassed the results obtained by ORNL. The primary discrepancy in the comparison occurs at the waste container-salt interface, where temperature rises obtained by ORNL are greater than those obtained with the finite-element model. This exception may be due to differences in the procedure for modeling the annular space between the waste container and the surface of the drillhole. It should also be noted that the temperature-rise values presented by ORNL involve a combination of two-dimensional (r-z) and three-dimensional (x-y-z) calculations, as compared to the two-dimensional (r-z) calculations obtained with RSI/TRANCO. In view of the various differences in model development, the comparison of results obtained with the

finite-element model utilized by RE/SPEC Inc. and the finite-difference models used by ORNL is quite favorable from a general point of view.

With regard to the New Mexico pilot-plant site, the temperature rise at the sleeve-salt interface achieves a maximum of approximately 260° after five years of heat generation, as indicated in Appendix B. This temperature rise is generally symmetrical with respect to the emplacement of the waste canister within the steel sleeve, and is a maximum (constant) over approximately 80% of the canister length. A maximum temperature rise of 1075°F occurs in the waste container after 0.5 year and approximately 60°F along the centerline of the pillar after nine years.

The analysis of the thermoelastic stress distribution in the near-field vicinity of the sleeve-waste container at the New Mexico pilot-plant site involve the use of several finite-element models with various boundary conditions, as indicated in Appendix C. In particular, for representation of limiting conditions of thermal expansion of the salt in the vicinity of the room and pillar, the following conditions were prescribed along the top boundary of a given finite-element model:

- (1) Case A: zero vertical displacement at the top of a model; this condition requires that the thermal expansion of the salt is entirely restricted to the immediate vicinity of the room.
- (2) Case B: top of a model subjected to overburden load; this condition implies that any vertical movement of the salt due to thermal expansion throughout the model is restrained only by the weight of the overburden.

These two conditions were utilized in order to effectively economize on the development of a finite-element model. Specifically, the models

represent a 75 foot vertical section through the room and pillar level; the conditions prescribed above provide limiting representations of the stiffness that would be achieved by including an additional 2000 feet of overburden rock. In addition, the following three extreme conditions were utilized to represent the existence of the steel sleeve in the drillhole:

- (1) the radial displacement of the salt at the sleeve-salt interface was specified as zero, while the vertical displacement was totally unrestricted by the presence of the steel sleeve (see Figure 1.A);
- (2) both the radial and vertical displacements at the sleeve-salt interface were specified as zero;
- (3) the drillhole was assumed to contain a solid steel cylinder.

The first and second conditions imply that perfect slip and perfect bonding, respectively, can exist at the interface, with negligible radial displacement at the interface due to the comparatively greater stiffness of the steel sleeve. The third condition permits an interaction between the steel and the salt, but implies that the steel sleeve is comparatively much stiffer than the salt. Schematic representations of the first and second limiting boundary conditions at the sleeve-salt interface are illustrated in Figure 1, along with the corresponding (qualitative) radial pressure distributions due to thermal and lithostatic loadings. In general, the radial pressure distribution developed at the interface between the salt and a solid steel cylinder will be qualitatively similar to that developed for the condition of perfect slip at the interface.

A tabulation of radial pressures at the sleeve-salt interface is given in Table 1 for the different model conditions after five years of

(A) UNRESTRICTED VERTICAL MOVEMENT BETWEEN SLEEVE AND SALT

(B) RESTRICTED VERTICAL MOVEMENT BETWEEN SLEEVE AND SALT

Figure 1. Schematic representation of various limiting boundary conditions of the sleeve-salt interface and the corresponding (qualitative) radial pressure distributions due to thermal and lithostatic loadings.

TABLE 1

Tabulation of Radial Pressure at the Sleeve-Salt Interface for
Different Model Conditions after 5 Years of Heating with a 5 KW Thermal Source

VERTICAL POSITION	DEPTH (FT.)	RADIAL PRESSURE AT SLEEVE-SALT INTERFACE					
		VERTICAL SLEEVE MOVEMENT UNRESTRICTED		VERTICAL SLEEVE MOVEMENT RESTRICTED		SOLID STEEL CYLINDER IN DRILLHOLE	
		CASE A	CASE B	CASE A	CASE B	CASE A	CASE B
<u>THERMAL STRESS</u>							
Floor level	2,000	900	775	3,830	4,000	1,450	1,350
Midpoint between Floor and Waste Can. Top	2,004	2,150	900	2,250	1,050	2,200	950
Waste Can. Top	2,008	2,550	1,250	2,250	950	2,725	1,475
Midpoint of Waste Can.	2,013	3,150	1,950	2,700	1,500	3,600	2,375
Base of Waste Canister (Approx.)	2,018	3,750	2,625	3,450	2,975	4,525	3,425
<u>LITHOSTATIC STRESS</u>							
Floor level	2,000	150	150	-2,000	-2,000	150	150
Midpoint between Floor and Waste Can. Top	2,004	1,675	1,675	1,400	1,400	1,675	1,675
Waste Can. Top	2,008	1,725	1,725	1,750	1,750	1,725	1,725
Midpoint of Waste Can.	2,013	1,575	1,575	1,600	1,600	1,575	1,575
Base of Waste Canister (Approx.)	2,018	1,850	1,850	1,875	1,875	1,850	1,850
<u>TOTAL STRESS</u>							
Floor level	2,000	1,050	925	1,850	2,000	1,600	1,500
Midpoint between Floor and Waste Can. Top	2,004	3,825	2,575	3,650	2,450	3,875	2,625
Waste Can. Top	2,008	4,275	2,975	4,000	2,700	4,450	3,200
Midpoint of Waste Can.	2,013	4,725	3,525	4,300	3,100	5,175	3,950
Base of Waste Canister (Approx.)	2,018	5,600	4,475	5,325	4,850	6,375	5,275

heating with a 5 KW source of thermal output. With regard to the level of the midpoint of the waste canister (2013 feet), the lithostatic load can give rise to a radial pressure of approximately 1600 psi. It must be emphasized that this condition can only develop as a consequence of immediately placing the sleeve in the drillhole prior to any elastic displacement, or as a consequence of creep relaxation with time in the salt. With regard to the same location on the sleeve, the thermal loading after five years may generate a radial pressure of 1500 psi for Case B to 3600 psi for Case A (where Case A and Case B refer to the boundary conditions at the top of the finite-element model). By superposing the stress states due to lithostatic and thermal loadings, a maximum radial pressure of approximately 3000 to 5000 psi could be developed on that portion of the steel sleeve surrounding the waste container. With due regard to the assumptions that were utilized in the development of the finite-element models, including the r-z geometry, these values must be recognized as being upper-bound estimates; the conditions in reality should be much less restrictive in all probability. Specifically, the assumption of a solid steel cylinder in the drillhole gives rise to a much greater thermal expansion of the steel than would be realized with a steel sleeve; as a consequence, the radial pressure distribution along the sleeve should be appreciably reduced. By the same token, the radial displacement at the sleeve-salt interface will be non-zero, and presumably inward; this aspect should have the effect of also reducing the maximum radial pressure on the sleeve.

APPENDIX ACOMPARISON OF RSI/TRANCO TEMPERATURE FIELDS
WITH ORNL RESULTS FOR THE LYONS, KANSAS SITE

In order to establish a quantitative comparison between the temperature fields generated by the RSI/TRANCO computer code and the results obtained by ORNL personnel, a finite-element model, designated as SALT-5/T, was developed in accordance with the dimensions specified in the ORNL-4789 report for the room and pillar configuration at the Lyons, Kansas site, and utilized with the thermal property and power data given in the same report. SALT-5/T is a two-dimensional r-z model, containing 252 elements and 151 nodes. The dimensions of the model, including the room, position of the waste container, and the location of the salt, shale, and salt-shale formation members, are shown in Figure A.1. The waste container is assumed to have a diameter of 6 inches, an initial zero temperature, and an initial thermal power output of 4.3767 KW with a decay constant of 0.023105 per unit time. The thermal power output was computed on the assumption that the waste had an age of ten years and a mass of 37.7 kilograms per unit of thermal power (see ORNL-4789, p. 45), and that an individual container held 165 kilograms of waste nuclides (see ORNL -4789, p. 55). Temperature distributions were computed for thermal conductivities that were experimentally determined at constant temperatures of 32°F and 392°F (see ORNL-4789, pp. 33-34), as given in Table A.1. The top boundary of the SALT-5/T model is maintained at zero temperature, and all of the remaining boundaries, including the void perimeter of the room, are assumed to be perfectly insulated.

Figure A.1. Schematic representation of the SALT-5/T finite element model used in RSI/TRANCO.

The temperature results for the two constant conductivities runs are plotted in Figure A.2 along with those presented in ORNL-4789 (see Figure 7.10., p. 55). With the exception of the waste container-salt interface, the temperature fields computed with RSI/TRANCO effectively bound the results obtained by ORNL. The comparatively greater temperature rises obtained by ORNL at the waste container-salt interface may be due to differences in the procedure for modeling the annular space between the container and salt surfaces. The time at which peak temperatures are achieved in the waste container and at the waste container-salt interface are comparable. However, peak temperatures along the centerline of the pillar appear to occur at an earlier time with the SALT-5/T model than observed by ORNL. It should be noted that the temperature-rise values presented by ORNL involve a combination of two-dimensional (r-z) and three-dimensional (x-y-z) calculations, as compared to the two-dimensional (r-z) calculations obtained with RSI/TRANCO. In view of this difference, the comparison of results obtained with the finite-element model utilized by RE/SPEC Inc. and the finite-difference models used by ORNL is generally quite favorable.

Figure A.2. Comparison of temperature distributions generated by RSI/TRANCO and those obtained by ORNL for the Lyons, Kansas site.

APPENDIX BTRANSIENT TEMPERATURE FIELD FOR THE ROOM AND PILLARCONFIGURATION AT THE NEW MEXICO PILOT-PLANT SITE

In order to determine the transient temperature field for the room and pillar configuration that is proposed for the New Mexico pilot-plant site, use was made of the SALT-6/T finite-element model shown in Figure B.1. SALT-6/T is a two-dimensional r-z model, containing 213 elements and 132 nodes. The width and height of the room are 18 feet and 18 feet, respectively, and the width of the pillar is 60 feet. The waste is assumed to have an initial zero temperature and an initial thermal power output of 5 KW with a decay constant of 0.023105 per unit time. The thermal conductivities of the waste and the salt were taken to be 0.25 and 2.43 BTU/hr.-ft.-°F, respectively (see ORNL-4789, pp. 33-34); the conductivity of salt corresponds to a temperature of 212°F. The top boundary of the SALT-6/T model is maintained at zero constant temperature and all of the remaining boundaries, including the perimeter of the room, are assumed to be perfectly insulated. The assumption that the perimeter of the room is perfectly insulated provides an upper bound on the induced temperature field.

The diameter and depth of the drillhole in the floor of the room was specified as 21 inches and 18 feet, respectively. The waste container is assumed to occupy the bottom 10 feet of the drillhole, as illustrated in Figure B.1. The jacket of the waste container and the steel sleeve were not included in the development of the model; the thermal resistance of these materials is small as compared to that of the salt. Rather, the power output of the waste was proportioned on a volume basis, according to the diameter of the drillhole and the height of the waste container.

Figure B.1. Finite-element grid for the room and pillar configuration at the New Mexico pilot-plant site.

For comparative purposes, a second finite-element model, designated as SALT-7/T, was developed in two-dimensional r-z geometry on the basis of 189 elements and 118 nodes. SALT-7/T has the same basic dimensions and boundary conditions as SALT-6/T, except that the mesh detail around the sleeve is expanded at the expense of the far-field mesh detail. The portion of the drillhole above the waste container in the SALT-6/T model is vacant, while the same portion in the SALT-7/T model is completely filled with steel.

The transient temperature distributions in the waste container, at the waste container (or sleeve)-salt interface, and along the centerline of the pillar are presented in Figure B.2 for a time period of 20 years. The waste container and waste container (sleeve)-salt interface attain maximum temperature rises of 1045°F and 236°F at 0.5 year and 4 years, respectively, for the SALT-6/T model, and rises of 1075°F and 258°F at the same times, respectively, for the SALT-7/T model. The temperature rise along the centerline of the pillar is maximum at 9 years; specifically, peak temperature rises of 57°F and 42°F occur at the waste and floor levels, respectively, with negligible differences between models. Although the results are not illustrated in Figure B.2, a second code run was made for a 6-inch diameter drillhole that contained waste with a thermal power output of 4.38 KW. In this instance, the peak temperature rises occurred essentially at the same times as observed for the 5 KW power output. However, with the exception of the waste container (sleeve)-salt interface, the rises were approximately 10% less than those obtained with the higher thermal output and larger diameter drillhole; the waste container (sleeve)-salt interface attained a maximum

Figure B.2. Time-dependent temperature rises at various locations in the finite-element (r-z) models for the New Mexico pilot-plant site.

temperature rise of 241°F, which is bracketed by the results for the SALT-6/T and SALT-7/T models.

The temperature rises along the sleeve-salt interface at times of 1, 5, and 20 years are shown in Figure B.3 for both models. Notably, the temperature rise is generally symmetrical with respect to the canister emplacement, and maximum (constant) over approximately 80% of the canister length. The temperature rise at any given time is approximately 8% greater in the immediate vicinity of the canister when the top portion of the drillhole is completely filled with steel (SALT-7/T model) as compared to the case when it is vacant (SALT-6/T model).

Figure B.3. Temperature rise along the sleeve-salt interface at various times.

APPENDIX CTHERMOELASTIC STRESS DISTRIBUTION IN THE NEAR-FIELD VICINITY
OF THE SLEEVE-WASTE CONTAINER AT THE NEW MEXICO PILOT-PLANT SITE

In order to determine the state of thermoelastic stress in the near-field vicinity of the sleeve-waste container, use was made of the SALT-6 and SALT-7 finite-element models. As indicated in Appendix B, these models were developed in two-dimensional r-z geometry according to the room, pillar, and waste-container drillhole dimensions appropriate for the New Mexico pilot-plant site. The total thermoelastic stress state may be separated into two discrete states, corresponding to the lithostatic loading and to the thermal loading. Furthermore, the steel sleeve-salt interface was represented by the following situations:

- (1) The radial displacement at the sleeve-salt interface was specified as being zero, while the vertical displacement was completely unrestricted; i.e., rollers were assumed to be positioned along the interface.
- (2) Both the radial and vertical displacements along the sleeve-salt interface were assumed to be zero.
- (3) The drillhole was assumed to contain a solid steel cylinder, thus permitting an interaction between the two components.

These "boundary conditions" represent extreme interaction situations between the steel sleeve and the salt, thereby providing maximum values for the radial pressure developed on the steel sleeve. In addition, the following conditions were assumed along the top boundary of the finite-element models for thermal loading conditions only:

- (1) Case A: zero vertical displacement at the top of the model;

this condition requires that the vertical displacement due to thermal expansion must be contained entirely within the vicinity of the room.

- (2) Case B: top of the model subjected to overburden load; this condition permits the upward expansion of the salt due to thermal loading, but is restrained by the weight of the overburden.

In general, the stress state due to thermal loading was computed for temperature distributions at 0.5, 1, 5, 10, and 15 years; as indicated in Appendix B, the maximum temperature rise at the sleeve-salt interface occurred at approximately 5 years. The salt in the finite-element models was assumed to have a density of 135 pcf, and the overburden to have a density of 142.5 pcf. The modulus of elasticity and Poisson's ratio were taken to be 4×10^5 psi and 0.4, respectively, for salt, and 30×10^6 psi and 0.29, respectively, for steel.

The radial pressure profile along the sleeve-salt interface due to lithostatic loading is illustrated in Figure C.1. It should be noted that the field stress in the radial direction is equal to approximately 67% of the vertical field stress that is generated by the weight of the overburden. The radial pressure on the sleeve at the midpoint of the waste canister is equal to approximately 1600 psi, or approximately 20% greater than the radial field stress; this value is in agreement with previous theoretical calculations of the radial stress "concentration" factor at the interface (see RSI-0007, p. 12). The radial pressure increases to approximately 1825 psi at about 6 feet below the floor of the room. If the vertical movement of the sleeve is entirely restricted, the radial pressure becomes tensile at the floor level; conversely,

Figure C.1. Radial pressure profile along the sleeve-salt interface due to lithostatic loading.

if the vertical sleeve movement is unrestricted, or the drillhole contains a solid steel cylinder, the radial pressure on the sleeve will be only about 150 psi at the floor level. Due to the geometry of the base of the steel sleeve, the radial pressure will be approximately 1850 psi.

As a note of caution in utilizing the radial pressure profiles presented in Figure C.1, it must be emphasized that these pressures will only occur if the steel sleeve is instantaneously inserted into the drillhole, i.e. prior to any radial displacement. Alternatively, these pressures may develop as a consequence of creep relaxation with time. In any event, these computations should only be considered in a limiting sense. The radial pressure profiles along the sleeve-salt interface after five years of heating are shown in Figures C.2 and C.3. The maximum radial pressure on the steel sleeve at the midpoint of the waste container ranges from 2700 psi to 3600 psi if the top of the finite-element model is restrained against vertical displacement, and from 1500 psi to 2375 psi if the top of the model is restrained only by the weight of the overburden. At floor level, the radial pressure varies from about 800 psi to 1500 psi for either Case A or Case B, ignoring the situation in which vertical movement of the sleeve is entirely restricted; this latter condition could give rise to radial pressures approaching 4000 psi if considered realistic. The radial pressure at the base of the sleeve will be approximately 20% greater than that at the midpoint of the waste container; however, these peak pressures are only approximate, and would probably be reduced by plastic yielding of the salt.

The radial stress distribution in the salt at approximately the midpoint level of the waste container is shown in Figure C.4. If the

Figure C.2. Radial pressure profile along the sleeve-salt interface due to 5 years of heating [Top of model restricted to zero vertical displacement].

Figure C.3. Radial pressure profile along the sleeve-salt interface due to thermal loading after 5 years of heating [Top of model subjected to overburden load].

Figure C.4. Radial stress distribution at a depth of 2,013 feet in salt after 5 years of heating (stress due to temperature field only).

vertical movement of the sleeve is restricted, the radial stress in the salt will achieve a maximum at approximately three radii from the sleeve-salt interface. Conversely, if the vertical movement of the sleeve is not restricted, the maximum radial stress occurs at the sleeve-salt interface.

The thermal stress state at the sleeve-salt interface, at the midpoint level of the waste container, is presented as a function of time in Figure C.5. For either Case A or Case B, all stresses appear to attain maximum values after approximately five years of heating. It is of interest to note that the tangential stress becomes the intermediate stress after approximately two years. In addition, the values of the individual stress components are increased by approximately 75% if the thermal expansion is completely contained within the immediate vicinity of the room.

Figure C.5. Stress state at the sleeve-salt interface as a function of heating time at a depth of 2,013 feet. [Solid steel cylinder in drillhole].

REFERENCES

Cheverton, R. D. and Turner, D.W., "Thermal Analysis of the National Radioactive Waste Repository", ORNL-4789 (1972).

Gnirk, P. F., Pariseau, W. G., Russell, J. E., Wawersik, W. R., Callahan, G. D., and Hovland, H.: "Analysis and Evaluation of the Rock Mechanics Aspects of the Proposed Salt Mine Repository", Summary Progress Report [RSI-0005], Prepared for the Oak Ridge National Laboratory [Union Carbide Corporation, Nuclear Division Subcontract No. 3706] (September 1973).

Gnirk, P. F., et. al., "Analysis and Evaluation of the Rock Mechanics Aspects of the Proposed Salt Mine Repository" Summary Progress Report [RSI-0002], Subcontract No. 3706, ORNL (1972).

Gnirk, P. F., "Elastic Solutions for Selected Circular-Symmetric Problems as Applied to the Design of the Waste-Container Sleeve", Technical Memorandum Report [RSI-0007], Subcontract No. 3706, ORNL (1974).