EVALUATION OF THERMAL AND STRUCTURAL COMPUTER CODES*

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ABSTRACT

A large number of thermal and structural codes exist which could be applied to the design and licensing of spent fuel shipping casks. This paper describes a program whose purpose was to provide information to designers that would aid them in making decisions regarding the selection of the most appropriate thermal or structural code for their particular design. The program was conducted in four phases: (1) Code inventory and evaluation (2) model problem development, (3) model problem solution, and (4) information exchange meeting. The current status of the program as well as its future direction is discussed.

INTRODUCTION

A large number of thermal and structural codes currently exist which could be applied to the design and licensing of nuclear material shipping casks. One of the problems which the designer of shipping casks faces is the decision regarding the choice of codes to be used. This decision is influenced not only by technical considerations, but may also be influenced by economic and even political considerations. The purpose of this program was to provide sufficient information on thermal and structural codes so that the cask designers decision regarding the use of a particular code would be based on as broad a spectrum of information as possible.

As part of its technology efforts, the Sandia National Laboratories Transportation Technology Center (SNL/TTC) has undertaken a program which will help provide information on a number of thermal and structural codes. By working with the nuclear transportation community in developing this information, it is felt that designers will have more information with which to make decisions regarding the technical adequacy of codes available to them.

A traditional means of evaluating code adequacy has been the "benchmarking" or comparison of code results against either exact analytical solutions or empirical data. This approach is satisfactory if the problem which the code is intended to model is amenable to analytic solution or has sufficient experimental data available against which to compare the various code results.

Unfortunately, the thermal and structural problems for shipping casks are sufficiently complex that exact analytic solutions or sufficient and reliable experimental data are not available. As a result, the approach chosen for the SNL/TTC effort was a "consensus" evaluation wherein, instead of using exact analytical solution or empirical data as a basis for comparison, a "consensus" code solution was used to make all code evaluations.

CODE EVALUATION PROGRAM

This program has been conducted in four phases which are briefly described below:

The first phase involved code inventories and evaluations which were conducted by the Sandia type B Packages exposed to the Hypothetical Accident Conditions[1]. Thermal and Structural Codes which could be used to model the Hypothetical Accident Conditions would ideally be publicly available, treat all the relevant thermal or structural physical parameters, provide reliable and accurate answers, be inexpensive to run, and would be "user friendly" to operate.

The second phase involved the definition of the model problems. Working together, the two labs developed a number of thermal and structural model problems, against which the codes would be evaluated. These model problems were to be simple, involve most of the important thermal and structural physical parameters, and be "cask-like" in nature.

The third phase involved the development of the consensus solutions for the model problems. In this phase, each of the labs worked in applying codes to the model problems and obtaining solutions. The results for each model problem were then compared and any differences resolved. Once the reasons for differences were understood and agreement on solutions was obtained, these results were adopted as those to which all subsequent code results would be compared during the information exchange phase.

The fourth phase of this activity involves a transfer of information between SNL/TTC and the nuclear material transportation community. This phase will consist of at least two information exchange meetings. The purpose of the first meeting was to discuss the first three phases of the program, and present the format to be used during the actual code informational exchange phase. After a reasonable period of time, during which the participants will solve the test problems using their own codes, a meeting will be held at which time information obtained by the SNL/TTC and the participants in running their codes would be exchanged.

The remainder of this report will describe, in more detail, each of the four phases of the SNL/TTC code evaluation program.

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PHASE I-CODE INVENTORY AND EVALUATION

The most stringent regulatory requirements governing the thermal and structural design of shipping casks are described in the code of Federal Regulations for National Laboratories, Albuquerque, New Mexico and Battelle Pacific Northwest Laboratories, Richland, Washington. Each lab inventoried a number of existing thermal and structural codes that were publicly available. Once the codes were inventoried they were reviewed to obtain as much information regarding each code's capability as possible.

With these concepts in mind, a search was conducted for publicly available computer codes advertising either thermal or structural capabilities. In all 44 codes (30 thermal and 14 structural) were identified for further evaluation. It is important to note that the 44 codes represent only those codes which were identified as being publicly available and for which we were able to obtain information regarding the codes capability during the time period when the Phase I work was going on. One should not infer that these codes represent the "best" or "only" codes available at the time. We are aware that we may have overlooked some codes, because of time and financial constraints under which we were operating at the time. However, that should not bias anyone negatively against any code that did not appear in our listing.

The matrices of thermal and structural code capabilities are shown in Tables I and II, respectively. All codes are available for public use either by purchasing or by paying a fee for use. Again, the code list is not claimed to be complete and other codes may be found or newer codes will evolve which should also be considered equally at the time that the particular cask design is required.

User manuals were obtained for each of the codes from which "advertised" capabilities were ascertained. The user manual information represents capabilities that can be readily identified for a particular code. In practice, however, the utility of a code for solving particular classes of problems is best determined by actual usage on those problems. Because advertised capabilities frequently need to be independently qualified to accurately define the practical capabilities of any code, the second and third phases of the code evaluation program were undertaken.

Phase II & III - Model Problem Definition and Evaluation

Based upon the thermal and structural code matrices, several codes with the widest range of capabilities were selected for more detailed evaluation. Eleven model problems (six thermal and five structural) of graduated complexity were developed for the code evaluation portion of the study. These models represented a compromise between realistic cask geometries and conditions, and computational simplicity. One of each of the thermal and structural model problems had an exact analytical solution so that the accuracy of each code could be checked directly. The remaining model problems are sufficiently complicated to preclude a closed form solution so that code consensus approach was used for each of the remaining thermal and structural problems. One of the thermal model problems is shown in Figure 1 and the problem input parameters for this problem are presented in Table III. One of the structural problems together with its problem input parameters is presented in Figure 2.

Phase IV - Information Exchange Meetings

A meeting was held on November 4 & 5, 1982 at the National Bureau of Standards, Gaithersburg, MD to inform other organizations of the work to date and to encourage participation in the code evaluation effort. The meeting was attended by 37 people from 23 organizations, 20 from the U. S. and 3 from Canada; with representation from 2 regulatory agencies (The U.S. Nuclear Regulatory Commission and The Canadian Atomic Energy Control Board) and 7 U.S. national laboratories. The philosophy used in developing the benchmark problems, the purpose of the program and the details of each problem were presented. This information was documented in a workshop report[2] which was distributed to all the participants. In addition, the attendees were asked to solve their thermal and structural problems using their own codes.

Results

As a result of the Code Evaluation Program, at least six organizations (two from Canada, two from industry and two from government laboratories) have already indicated that they would participate in the code evaluation activity subject to their management's approval. Because all solutions to the problem presented have not yet been received, none of the problem solutions have been presented in this paper. The solutions will be presented at a second meeting during which the industry representatives will present the results they obtained in solving the thermal and structural problems. These interactions will establish the utility of a large number of thermal and structural codes and should serve to develop information regarding the applicability of the codes to shipping cask design.

REFERENCES

1. "Packaging of Radioactive Material for Transport and Transportation of Radioactive Material under Certain Conditions," U. S. Nuclear Regulatory Commission Rules and Regulations, Title 10, Code of Federal Regulations, Part 71, Revised As of January 1, 1982.

2. J. M. Nelsen, "Industry/Government Joint Thermal and Structural Codes Information Exchange Meeting," SAND82-2786/TTC-0404 Sandia National Laboratories, Albuquerque, New Mexico

TABLE I

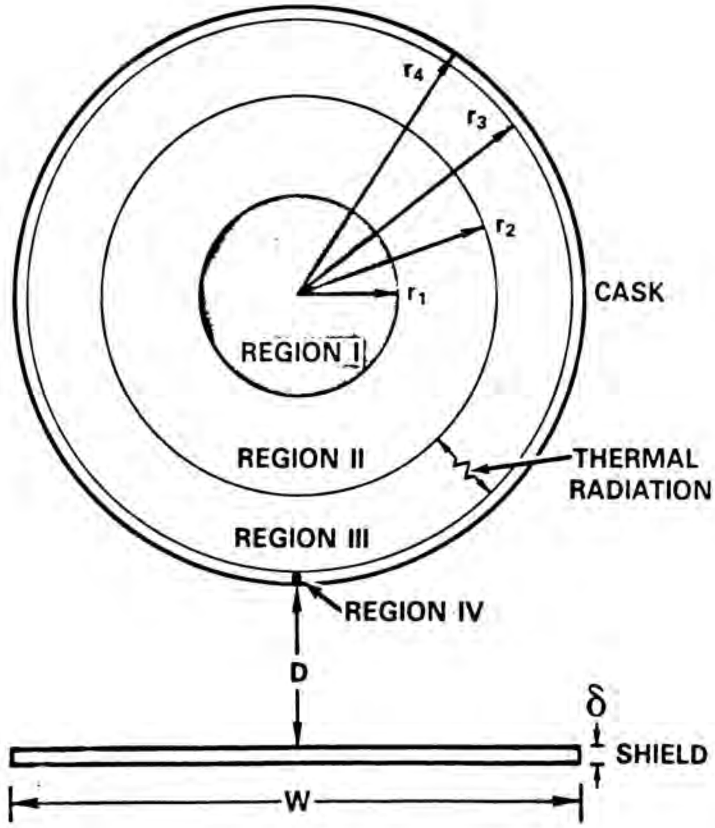
THERMAL ANALYSIS CODE SURVEY

CAPABILITY / COMPUTER CODE NAME	GEOMETRY						BOUNDARY CONDITIONS						SOLUTION ALGORITHMS							SOLUTION CAPABILITIES											MISCELLANEOUS				
	DIMENSIONALITY	CARTESIAN	CYLINDRICAL	IRREGULAR CELL	VARIABLE GRID	SIZE LIMITS	TRANSIENT B.C.	TEMPERATURE	HEAT FLUX	CONVECTION	RADIATION	COMBINATIONS	STEADY STATE	TRANSIENT EXPLICIT	TRANSIENT IMPLICIT	SPECIAL STEADY STATE OPTION	FINITE DIFFERENCE	FINITE ELEMENT	AUTOMATIC TIME STEP	CONDUCTION	CONVECTION	RADIATION	COMPUTED CONVECTION	HEAT GENERATION	VARIABLE PROPERTIES	PHASE CHANGE	PHASE CHANGE + CONVECTION	MULTIPLE MATERIALS	COMPANION STRUCTURAL CODE	RESTART	AGE	DATA CARD INPUT	AVAILABLE ON OTHER MACHINES	INTERNAL GRAPHICS
ADINA-T	1,2,3	Y	Y	Y	Y	?	Y	Y	Y	Y	Y	Y	Y	Y	Y	?	N	Y	?	Y	N	N	N	Y	Y	N	N	Y	Y	Y	4	Y	Y	N
HEATING-5	1,2,3	Y	Y	N	Y	10000	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N	N	N	Y	Y	Y	N	Y	N	Y	5	Y	Y	N
SARFIN																																		
ORTHIS/ORTHAT	1,2	Y	Y	N	N	?	Y	Y	Y	Y	Y	?	Y	Y	?	?	Y	N	?	Y	N	N	N	Y	?	Y	N	Y	N	N	11	Y	?	N
NACHOS	1,2	Y	Y	Y	Y	?	Y	Y	Y	Y	Y	?	Y	Y	N	N	N	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	5	Y	N	Y
MOXY																															12			
APACHE/MATUS	1,2,3	Y	Y	Y	Y	4000	Y	Y	Y	Y	Y	Y	Y	Y	?	?	N	Y	?	Y	N	N	N	Y	Y	N	N	Y	Y	Y	9	Y	?	Y
HEX																															9			
CINDA-3G	1,2,3	Y	Y	Y	Y	4100	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	?	Y	Y	Y	N	Y	Y	Y	N	Y	N	Y	15	?	?	?
MORSE-SGG																															5			
THTD-THTE	1,2,3	Y	Y	Y	Y	?	Y	Y	Y	Y	Y	Y	Y	Y	Y	?	Y	N	?	Y	Y	N	N	Y	Y	?	N	Y	N	?	16	Y	?	N
RAT-3D	1,2,3	Y	Y	N	Y	512	Y	Y	Y	Y	Y	Y	N	Y	Y	N	Y	N	?	Y	N	N	N	Y	Y	N	N	Y	N	Y	10	?	?	N
TAC-3D	1,2,3	Y	Y	N	Y	1728	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	?	Y	Y	N	N	Y	Y	N	N	Y	N	Y	10	?	?	N
TOSS	1,2,3	Y	Y	Y	Y	?	Y	Y	Y	Y	Y	Y	Y	Y	Y	?	Y	N	?	Y	N	N	N	Y	Y	N	N	Y	N	?	10	?	?	N
TRUMP	1,2,3	Y	Y	Y	Y	1000	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	N	Y	Y	Y	N	Y	N	Y	10	Y	Y	N
HEATRAN	1,2	Y	Y	Y	Y	1100	Y	Y	Y	Y	Y	Y	Y	Y	Y	?	N	Y	?	Y	Y	N	N	Y	Y	[illegible]	?	Y	?	?	?	?	?	?
HOT-2D	1,2	Y	Y	?	?	5000	Y	Y	Y	Y	Y	Y	Y	Y	?	?	Y	N	?	Y	N	N	N	Y	Y	N	N	Y	N	?	10	?	?	N
TAC-2D	1,2	Y	Y	N	Y	2025	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	?	Y	Y	N	N	Y	Y	N	N	Y	N	Y	10	?	[illegible]	N
COYOTE	1,2	Y	Y	Y	Y	?	Y	Y	Y	Y	Y	Y	Y	Y	Y	?	N	Y	?	Y	N	N	N	Y	Y	N	N	Y	N	Y	4	Y	N	Y
TEMPEST	1,2,3	Y	Y	N	Y	6000	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	N	Y	N	Y	4	Y	Y	Y
HYDRA	1,2,3	Y	Y	N	Y	8000	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	N	Y	N	Y	3	N	?	Y
COMMIX	1,2,3	Y	Y	N	Y	?	Y	Y	Y	Y	N	N	Y	Y	N	N	Y	N	Y	N	Y	N	Y	Y	Y	N	N	Y	N	Y	4	Y	N	Y
TACO	1,2	Y	Y	Y	Y	?	Y	Y	Y	Y	Y	Y	Y	Y	Y	?	N	Y	?	Y	N	Y	N	Y	Y	Y	N	Y	N	?	?	?	?	Y
TEMP N TEMP	1,2	Y	Y	Y	Y	?	Y	Y	Y	Y	Y	?	Y	Y	?	?	N	Y	?	Y	Y	Y	N	Y	Y	N	N	Y	Y	?	?	?	?	?
TRANCO	1,2	Y	Y	Y	Y	?	Y	Y	Y	Y	N	N	Y	Y	N	N	N	Y	?	Y	Y	N	N	Y	Y	N	N	Y	N	?	?	?	?	Y
MARC	1,2,3	Y	Y	Y	Y	?	Y	Y	Y	Y	Y	Y	Y	Y	?	?	N	Y	Y	Y	?	?	N	Y	Y	N	N	Y	Y	Y	9?	Y	?	Y
NASTRAN	1,2,3	Y	Y	Y	Y	?	Y	Y	Y	Y	Y	?	Y	Y	?	?	N	Y	?	Y	?	Y	N	Y	Y	N	N	Y	Y	?	?	?	?	?
COUPLEFLOW	1,2	Y	Y	Y	Y	?	Y	Y	Y	?	?	?	Y	Y	?	?	N	Y	?	Y	Y	N	Y	Y	Y	N	N	Y	N	?	11	Y	?	?
STMIR	1,2	Y	Y	N	Y	?	Y	Y	Y	?	?	?	Y	Y	Y	?	Y	N	N	Y	?	[illegible]	N	Y	Y	N	N	Y	N	?	5	Y	?	?
CONRAD	1,2	Y	N	N	Y	?	Y	Y	Y	Y	Y	?	Y	Y	N	?	Y	N	?	Y	Y	Y	N	Y	Y	N	N	Y	N	?	6	?	?	?

TABLE II

STRUCTURAL ANALYSIS CODES SURVEYED

Capability / Code Name	Code Type	Material Interface Treatment	Code Availability	Dimensionality	Time Integration Method	Time Step Selection	Self-contained Graphics	Restart Capability	Material Nonlinearity	Geometric Nonlinearities	Eulerian or Lagrangian	Initial Velocity Specification	Thermal Strains	Inertial Representation Lumped Consistent	Companion Thermal Code
ANSYS	FE (Finite Element)	G (Gap)	Fee for Use	1,2,3	I (Implicit)	US (User selected)	Y (Yes)	Y	Y	Y	L	Y	Y	C (Consistent)	Y (ANSYS)
HONDO II	FE	SL (Slide Line)	Free SNL Argonne	1,2	E (Explicit)	CS (Code selected)	N (No)	Y	Y	Y	L	Y	N	L (Lumped)	N
IMPAC 2	FE	N/A (Not Applicable)	Free LANL Argonne	1	I	US	N	N	Y	Y	L	Y	N	L	N
SHOCK	LP (Lumped Parameter)	N/A	Free SNL Argonne	1	I	US	N	N	N/A	N/A	L	Y	N	L	N
MARC	FE	SL	Fee for Use	1,2,3	I,E	US	Y	Y	Y	Y	L	Y	Y	C	Y (MARC HEAT)
NIKE2D	FE	SL	Free LLL	1,2	I	US	N	Y	Y	Y	L	Y	Y	L,C	Y (TACO)
DYNA2D	FE	SL	Free LLL	1,2	E	CS	N	Y	Y	Y	L	Y	Y	L	Y (TACO)
NONSAP	FE	G	Purchase U.C. Berkeley	1,2,3	I	US	N	Y	Y	Y	L	Y	N	L,C	N
PISCES	FD (Finite Difference)	SL	Fee for Use	1,2,3	E	US,CS	Y	Y	Y	Y	L,E	Y	N	N/A	N
ADINA	FE	G	Purchase ADINA Engineering, Inc.	1,2,3	I,E	US	N	Y	Y	Y	L	Y	Y	L,C	Y (ADINAT)
NASTRAN (Pre level 62)	FE	G	Purchase	1,2,3	I	US	Y	Y	N	N	L	Y	Y	L,C	Y
SAP4	FE	N (None)	Purchase Fee Berkeley	1,2,3	I	US	N	Y (modal Analysis only)	N	N	L	N (only Zero Initial Velocity)	Y	L	N
ABACUS	FE	G	Purchase Hibbet Karlsson Sorenson Inc.	1,2,3	I	US,CS	Y	Y	Y	Y	L	Y	Y	C	Y
DYNA3D	FE	SL	Free LLL	1,2,3	E	US	N	Y	Y	Y	L	Y	N	L	N



MODEL PROBLEM 4 - CASK WITH ANNULAR REGION AND SHIELD

FIGURE 1.

TABLE III Model Problem 4 - Cask With Annular Region and Shield

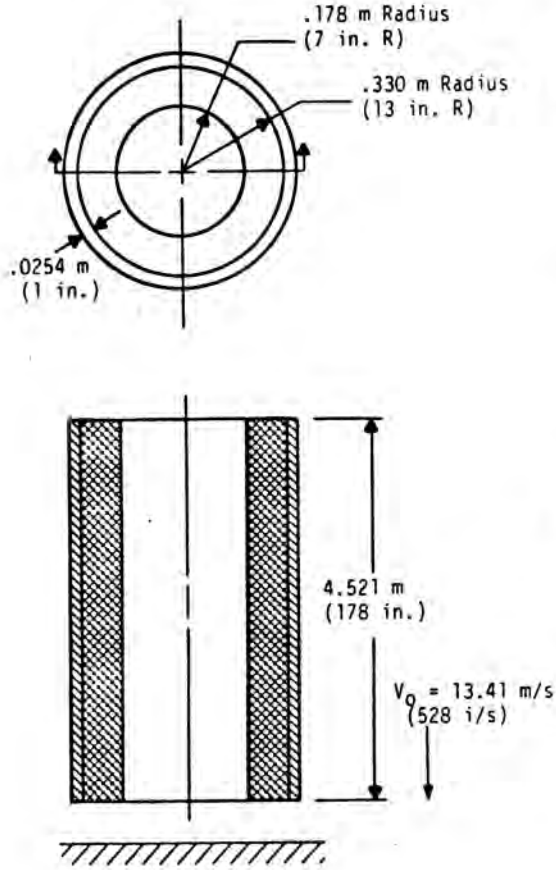
Region	Description	Thermal Characteristics	
I	Inner Region With Internal Heat Source, r_1=16.51 cm (6.5 in)	ρ=2707 kg/m^3 C_p=0.214 cal/gm-°C k=0.242 kw/m-°C Q=38.32 kw/m^3	(169 lbm/ft^3) (0.214 Btu/lbm°F) (139.7 Btu/hrft°F) (3702.6 Btu/ft^{3}hr)
II	Gamma Shield, Steel Construction, r_2=38.74 cm (15.25 in)	ρ=7832.8 kg/m^3 C_p=0.113 cal/gm-°C k=0.045 kw/m-°C	(489 lbm/ft^3) (0.113 Btu/lbm°F) (26 Btu/hrft°F)
III	Neutron Shield, Voided Region, r_3=53.98 cm (21.25 in)	Voided, Annular Enclosure, Non-participating Media, Radiant Exchange between Regions II and IV	
IV	Neutron Shell, Steel Construction, r_4=54.61 cm (21.5 in)	ρ, C_p, k	Same as Region II
Shield	Intervening Radiation Shield, Steel Construction, W=109.2 cm (43 in) δ=2.54 cm (1 in) D=30.48 cm (12 in)	ρ, C_p, k	Same as Region II

Environment Temperature

Ambient Environment, Steady-state:	t = 0	T_∞ = 54.4°C (130°F)
Fire Environment, Transient:	0 < t < 30 min	T_∞ = 800°C (1475°F)
Ambient Environment, Transient:	30 < t < 90 min	T_{∞_1} = 54.4°C (130°F)

Radiation Properties

$\epsilon = \alpha = 1$ (All surfaces and environment considered black)



Material Properties
(Elastic/Perfectly Plastic Steel)
(Elastic/Perfectly Plastic Lead)

Steel

Young's Modulus:

$E = 1.9305 \times 10^5$ MPa
(28×10^6 psi)

Poisson's Ratio:

$\nu = .3$

Density:

$\rho = 8.027 \times 10^3$ Kg/m^3
(.29 lbm/in.^{3})

Yield Stress:

$\sigma_y = 2.068 \times 10^2$ MPa
(30 ksi)

Lead

Young's Modulus:

$E = 1.3789 \times 10^4$ MPa
(2×10^6 psi)

Poisson's Ratio:

$\nu = .45$

Density:

$\rho = 1.135 \times 10^4$ Kg/m^3
(.41 lbm/in.^{3})

Yield Stress:

$\sigma_y = 13.78$ MPa
(2.0 ksi)

FIGURE 2. Input Data for Benchmark Model E