3/4/02

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3.0 WORK TO BE PERFORMED AND EXPECTED RESULTS

A. Scope of Work

The response of spent fuel transportation and storage casks and of the spent fuel carried or stored in these casks to sabotage attack scenarios and the radiological consequences that these scenarios might cause will be investigated. Initially the crash of a large jetliner fully loaded with jet fuel or a small plane packed with [redacted] (1) into a NAC-UMS rail cask and (2) into an array of HI-STORM storage casks will be modeled. The damage caused to the casks by the impact of the plane, the explosive [redacted] forces, and any jet fuel fire will be examined. The results of the plane impact calculations will be used to develop a simple model of a jetliner suitable for use with a desktop computer.

The number of rods in the NAC-UMS or the HI-STORM cask failed by the impact [redacted] and any ensuing fire and the amounts of fission products released from each failed rod will be estimated. Transport of the released fission products through the cask to the environment will be modeled to develop a source term for the radiological consequence calculations. These results and results developed by an expert panel will be used to develop simple source term models for spent fuel cask sabotage events.

Finally, the response of eleven additional transport and storage casks to sabotage scenarios specified by the NRC will be analyzed using simple cask models that can be run on a desk top computer, the radioactive source terms released by these sabotage scenarios will be estimated using the source term models developed by the expert panel supplemented by fission product transport calculations where appropriate, and the radiological consequences caused by the release of these source terms will be estimated by performing consequence calculations.

B. Recommended Approach

The mechanical loads experienced by the NAC-UMS and HI-STORM casks due to impact of the jetliner will be examined using the ZAPOTEC and PRONTO codes. ZAPOTEC uses a domain decomposition approach for simulation of continuum dynamics problems in which some portions of the calculation are treated with a Lagrangian scheme and other portions are treated in an Eulerian mode. Zapotec incorporates algorithms that perform a timestep-by-timestep coupling of these Lagrangian and Eulerian regions. One distinguishing feature of the ZAPOTEC methodology is that it enables a straightforward treatment of impact calculations where crushing of material in Lagrangian mesh elements produces mass that is best tracked using an Eulerian computational scheme. Specifically, simulation control of the distorted material is transferred from the Lagrangian mode to the Eulerian mode on an element-by-element basis and at the appropriate timestep in the calculation.

Currently, the PRONTO Lagrangian code and the CTH Eulerian code are the underlying codes in the ZAPOTEC architecture. PRONTO, is a SNL developed transient-dynamic finite element code (similar in scope to DYNA-3D) that can analyze large deformations of highly nonlinear materials subjected to high strain rates. CTH is an Eulerian shock code developed at SNL to solve large deformation, strong shock wave, solid mechanics problems.

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ZAPOTEC will be used to predict the damage done to arrays of casks by jetliner impact and either ZAPOTEK or PRONTO will be used to predict the damage done to individual casks by specific jetliner structures of concern (engines, landing gear, central wing structure, fully loaded center fuel tank). The CTH code will be used to predict cask damage caused by sabotage scenarios that involve the detonation of . The response of the cask and its fuel rods to fires will be examined using the VULCAN fire code and either the COYOTE or the ANSYS/Mechanical thermal heat transport code. Ex 2

The mechanical and thermal loads that these calculations indicate will be experienced by the package contents (e.g., spent fuel rods, radioactive wastes, sealed sources) will be used to estimate for example, the number of rods that are failed by the sabotage scenario. The release of fission products from failed rods will then be estimated using the best estimate release methodology developed for the NUREG/CR-6672 study. The source term methodology developed for this study by the expert panel will be used to estimate the release of radioactive materials to the cask interior from radioactive wastes and damaged sealed sources.

The eleven additional packages that will be examined by this study are the NAC-NLI-1/2 truck cask, the HI-STAR rail cask, the NUHOMS 32P storage cask, the TN-68 rail/storage cask, the VSC-24 storge cask, and the BUSS R-1, CNS 1-13C II, BW-2901, A-0109 Irradiator, CI-20WC-2, and TRUPACT-II radioactive material transportation packages. Wherever possible, the mechanical and thermal response of these packages will be modeled using simple models of each package initially constructed using SOLIDWORKS and then modified to be run respectively on a desktop computer using the ANSYS/LS-DYNA or ANSY/Mechanical computer codes. For the HI-STORM, HI-STAR, and NAC-UMS casks, these simple models will be developed using the detailed models of these casks previously constructed for use with the ZAPOTEK, PRONTO, and/or CTH codes as a starting point. Specifically, the detailed models constructed to support the ZAPOTEK, PRONTO, and/or CTH analyses will be simplified by eliminating unimportant structures and representing important structures by continuum, shell, or truss elements.

Transport of fission products through spent fuel casks and canisters and retention of fission products by deposition onto canister and cask surfaces will be modeled using MELCOR, a compartment code that implements a full suite of thermal-hydraulic and fission product transport models.. Fission product release to package interiors for sabotage scenarios that involve other radioactive materials will be estimated using the expert panel methodology, engineering judgment, and/or the results of MELCOR calculations. Then, having estimated the radioactive environmental source term caused by a sabotage scenario, the radiological consequences that might be caused by the environmental release will be estimated for railsite scenarios using the MACCS consequence code and for sabotage attacks on casks or packages during transport using the RADTAN consequence code.

C. Technical Considerations

The timetable specified for this program by NRC is ambitious. To meet the timetable, task work will need to proceed at one man-week of work per elapsed week of time for each person working on the project, and significant unanticipated problems must not occur. Though optimistic, the

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availability of modern parallel processing computers and of coupled Lagrangian/Eulerian impact analysis codes, specifically the SNL ZAPOTEC code, which couples a Lagrangian code PRONTO to an Eulerian code CTH, mean that the NRC schedule may be attainable. Running ZAPOTEC calculations on a parallel processing computer should allow most impact calculations to be performed in a few days with few runs aborted by program crashes. Program crashes should be minimized because ZAPOTEC passes the mass and momentum in highly distorted PRONTO Lagrangian mesh elements to CTH. Thus, mass and momentum are conserved and the "death" of highly distorted Lagrangian mesh elements is smoothly handled without causing the code to crash.

The development of simplified ANSY/LS-DYNA models of a large jetliner will be performed by first developing a detailed PRONTO model of the airplane, simplifying that PRONTO model, and finally converting the simple PRONTO model to an ANSYS/LS-DYNA model. This process will also be used to develop simple cask models for the HI-STAR transportation and HI-STORM storage casks. For all other casks, the modeling results for the HI-STAR and HI-STORM cask will be used to guide the development of simple ANSY/LS-DYNA cask models without having a detailed cask model to use as a starting point.

The impact and [redacted] models that will be developed for each cask will use and should use the initial undamaged geometry of the cask, since analysis of the effects on the cask of the impact or the [redacted] will determine the final damage state of the cask caused by these loads. However, construction of thermal and fission product transport models for undamaged cask geometries may introduce inefficiencies into the modeling process, since before these models can be used they will need to be modified to reflect the changes in cask geometry caused by the aircraft impact or the [redacted] that characterizes the sabotage scenario being analyzed. If these changes in geometry are minor, then modification of the undamaged thermal and fission product transport cask models will be easily accomplished. However, if the cask geometry is greatly changed by the impact or the [redacted] then the thermal and the fission product transport cask models may need to be almost totally reconstructed.

D. Tasks

This section describes each program task, specifies the task deliverable (if any), and presents estimates of the task completion date and of the level of effort and computational, travel, and/or subcontract costs required to complete the task. Because many of the tasks require complicated analyses, use recently developed computer codes, depend on results developed by other tasks, and/or will be performed by SNL staff with other programmatic commitments, task completion dates are uncertain and as quoted probably optimistic.

Task 0: **Program Initiation Meeting (8 MWs)**

SNL staff will develop overview presentations of the methods of analysis that Sandia believes provide the best approach to completing the program tasks on the schedule specified for the program. The recommended approach will be presented to NRC and discussed in detail at a review meeting in the NRC offices in Rockville MD. If appropriate, based on the discussions held at this meeting, SNL will revise this proposal and resubmit it to NRC for approval.

Deliverable: Program Review Meeting
Completion Date: Completed

Ex 2 portions

Task 1: ***Terrorist Events Initiated by Aircraft Crashes and Their Consequences***

Task 1.1: **Large Jetliner Crash into an Independent Spent Fuel Storage Installation**

Task 1.1A: **Mechanical Analyses**

Structural models of a Holtec HI-STORM storage cask, of a [redacted] and of the components of that jetliner that might damage the HI-STORM cask should the jetliner collide with the cask will be developed and used to estimate the cask damage that might be caused by the collision. Before being used to perform calculations, all models will be provided to NRC for review and then questions regarding the models discussed during a conference call.

Task 1.1Ai: **Crash of a Large Plane into a Field of Casks (4 MWs)**

The crash of a [redacted] into a field of storage casks will be modeled using the ZAPOTEC code. Although the exact size of the field of casks is not yet determined, fields as large as 100 by 100 may be considered. For this analysis, the jetliner will be modeled as a deformable structure and initially relatively simple cask structural models will be used to determine the global effects of the aircraft impact into the field of casks. The response of the aircraft and the casks developed by these analyses will be used to identify the jetliner crash scenarios that will be examined by Task 1.1Aiii below.

Task 1.1Aii: **PRONTO Models of the HI-STORM cask, an Aircraft Engine, an Aircraft Landing Gear, and an Aircraft Central Wing Structure (8 MWs)**

More detailed PRONTO finite element models, that can be used as input to the ZAPOTEC code, will be constructed for the Holtec HI-STORM spent fuel storage cask (2 MWs) and also for those airplane structures shown by Task 1.1Ai to be of concern. Depending on the results of Task 1.1Ai, detailed models may be constructed for a [redacted] jet engine (3 MWs), a [redacted] landing gear (1 MW), and the central wing structure of a [redacted] (2 MWs). The detailed models constructed by this task will be used in Task 1.1Aiii to determine the detailed response of the HI-STORM cask to high speed impacts by the aircraft structures of concern.

Task 1.1Aiii: **ZAPOTEC and PRONTO Finite Element Cask Collision Calculations (6 MWs)**

The sabotage scenarios identified as important by Task 1.1Ai and detailed cask and aircraft structure models developed by Task 1.1Aii will be used to define the ZAPOTEC and PRONTO finite element calculations that will be performed by this task to determine the specific damage that the sabotage scenarios of concern might cause to the HI-STORM storage cask. Additional ZAPOTEK and PRONTO analyses may be performed, if the results developed by this task or by Task 1.1Ai indicate that other scenarios (e.g., a cask colliding with a cask) are of importance.

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Task 1.1Aiv: Detailed ZAPOTEC Model of a Fully Loaded Jetliner Center Fuel Tank (1 MW)

A detailed ZAPOTEC model of a [redacted] center fuel tank that is fully loaded with jet fuel will be constructed.

Task 1.1Av: ZAPOTEC Center Fuel Tank Collision Calculations (2 MWs)

ZAPOTEC will be used to perform a detailed analysis of the collision of a [redacted] center fuel tank that is fully loaded with jet fuel with a HI-STORM cask.

Task 1.1Avi: Evaluation of Canister Performance (2 MWs)

The results of Tasks 1.1Ai through 1.1Av will be used to analyze the performance of the HI-STORM cask canister when the cask is subjected to extra-regulatory impact or thermal loads. Four possible canister failure modes will be examined: (1) failure due to deformation of the canister closure, (2) failure due to tearing of the canister body, (3) failure due to puncture of the canister body, and (4) failure due to burst rupture caused by heating in a fire. The starting point for this analysis will be the ZAPOTEC results developed by Tasks 1.1Aiii and 1.1Av. Wherever these results do not directly predict canister performance, they will be supplemented by hand calculations and expert judgement..

Deliverable: Letter Report documenting Task 1.1A
Completion Date: July 15, 2002

Task 1.1B: Thermal Analyses

Thermal models of damaged and undamaged Holtec HI-STORM storage casks will be constructed and used to model the response of the cask and its spent fuel to a jet fuel fire. Before being used to perform calculations, all models will be provided to NRC for review and then questions regarding the models discussed during a conference call.

Task 1.1Bi: Estimation of Amount of Jet Fuel in Fireball and Pool Fire (2 MWs)

The crash of a jetliner usually produces a fireball that consumes most of the plane's jet fuel. Because the fireball is of short duration, it does not pose a threat to a spent fuel cask. However, if substantial quantities of fuel escape the fireball, ignition of this fuel cold produce a pool fire of concern. The fraction of the fuel on board a jetliner that crashes into a spent fuel storage facility that is consumed by the crash fireball and the fraction that might escape to form a pool fire will be estimated by review of literature and consultations with aviation crash experts.

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Task 1.1Bii: Analysis of Canister Failure Temperature (2 MWs)

HI-STORM cask canisters not failed by crash impact loads may be able to fail by burst rupture if the canister can be heated to high enough temperatures. The behavior of the canister, when subjected to a fully engulfing, optically dense, long duration jet fuel fire, will be determined by performing P/Thermal calculations using the JAS 3D code. In particular, the pressure required to fail the canister by burst rupture, the temperature that produces this pressure, and the heating time in a jet fuel pool fire needed to reach this temperature will be determined.

Task 1.1Biii: Time to Rod burst Rupture

Spent fuel rods not failed by the crash impact loads may fail by burst rupture due to heating in an ensuing jet fuel pool fire.

Task 1.1Biii(a): Undamaged Cask/Canister

The durations of a fully engulfing, optically dense, jet fuel pool fire full required to cause spent fuel rods in the HI-STORM canister to fail by burst rupture will be calculated using the VULCAN computational fluid dynamics fire code, analytical heat transport correlations, and/or the COYOTE finite element heat transport code, first for the bare undamaged canister and then for the undamaged canister inside of the undamaged HI-STORM storage overpack.

Task 1.1Biii(a1): Construct Models (3 MWs)

Computer models for both the bare canister and the HI-STORM overpack will be constructed for use with the VULCAN and COYOTE codes.

Task 1.1Biii(a2): Run Calculations (3 MWs)

The duration (heating time) of an optically dense, fully engulfing, jet fuel pool fire needed to heat spent fuel rods in the HI-STORM canister to burst rupture temperatures will be determined by performing fire calculations using the VULCAN fire code, analytic correlations, and/or the COYOTE heat transport code. The calculations will be performed for the bare canister and also for the canister inside of the HI-STORM overpack.

Task 1.1Biii(b): Damaged Cask/Canister (17 MWs)

The results developed by the mechanical analyses performed for Task 1.1 A for a jetliner crash into a field of HI-STORM storage casks will determine the damage done to the cask and the canister housed in the cask by impact onto the cask of a jetliner engine, landing gear, or fully loaded center fuel tank. This task will develop thermal models of the damaged cask and canister and will use the models to calculate the fire durations that will heat spent fuel rods in the canister to rod burst rupture temperatures. If the cask and canister damage states caused by engine, landing gear, and center fuel tank collisions are quite different, then each damage state will be analyzed. If they are quite similar, then only the worst damage state will be examined.

Deliverable: Letter Report documenting Task 1.1B
Completion Date: August 31, 2002

Task 1.1C: **Rod-to-Cask Source Terms** (4 MWs)

The results developed by Tasks 1.1A and 1.1B will be used to estimate the damage state of the spent fuel in the HI-STORM storage casks, that might result from the large plane crash examined by these tasks. Release fractions for Noble Gases (Kr, Ar), Cesium compounds (e.g., CsI, CsOH, Cs_2O), Ruthenium compounds (e.g., RuO_4), CRUD, and Particulates will be developed for this spent fuel damage state using the release methodology documented in NUREG/CR-6672, first for the engine crash scenario and then for the landing gear and the center fuel tank crash scenarios.

Task 1.1D: **Fission Product Transport**

The MELCOR thermal hydraulic/fission product transport code will be used to estimate the transport of fission products through the HI-STORM cask/canister, including deposition of fission products onto cask/canister interior surfaces and release to the environment of fission products that do not deposit onto these surfaces. Technical concerns about the use of the MELCOR code to model fission product transport inside of a failed cask/canister will be discussed by SNL staff with NRC staff during a conference call before this task is initiated.

Task 1.1Di: **Undamaged Cask/Canister** (1 MW)

Fission product transport will first be estimated for transport through a HI-STORM storage cask/canister which has lost containment (e.g., puncture failure) but not been significantly deformed by the large plane crash (i.e., cask/canister internal volumes and surface areas are not significantly altered by the crash). This task will assume that all of the rods in the cask fail and will use results previously developed for the HI-STORM cask by NRC project J5160.

Task 1.1Dii: **Damaged Cask/Canister** (12 MWs)

The HI-STORM MELCOR input deck developed previously for NRC project J5160 will be modified as is appropriate to reflect the effects of the large plane crash (effects of cask/canister damage on cask/canister internal volumes and surface areas; fraction of spent fuel rods that fail) and then fission product transport through the damaged cask/canister will be examined for the damage produced by the engine impact (6 MWs), landing gear impact (3 MWs), and center fuel tank impact (3 MWs) scenarios.

Deliverable: Letter Report documenting Task 1.1C and 1.1D
Completion Date: September 30, 2002

Task 1.1E: **Consequence Calculations (4 MWs)**

The MACCS code will be used to estimate the radiological consequences that would result from the hypothetical accident scenarios examined by Tasks 1.1A through 1.1D. Population data for these calculations will be developed by performing POPSEC calculations using 2000 census data. Meteorological data will be obtained from two sources: (a) from a site wind rose if one is available, and (b) from the MACCS MET file for the nearest National Weather Service Station. Because the sabotage attack may cause radioactive materials to be released to the environment before an emergency evacuation can be carried out, possible emergency response actions will be reviewed to develop MACCS emergency response input. Technical concerns about the use of the MACCS code to model the consequences of radioactive releases to the environment for airplane crash sabotage scenarios will be discussed by SNL staff with NRC staff during a conference call before this task is initiated.

Deliverable: Letter Report documenting Task 1.1E
Completion Date: September 30, 2002

Task 1.1F: **Final Report (6 MWs)**

The results of Tasks 1.1A through1.1E will be documented in a report by combining and amplifying the letter reports for these tasks thereby producing a Final Report that documents all of the results developed by Task 1.

Deliverable: Task 1.1 Draft Final Report
Completion Date: October 31, 2002

Task 1.1G: **Computer Code Demonstration Meeting (9 MWs)**

SNL will prepare illustrative PRONTO, ZAPOTEK, CTH, ANSYS/LS-DYNA, JAS 3D, COYOTE, VULCAN, MELCOR, and MACCS calculations that demonstrate the use of these codes to analyze sabotage scenarios. The illustrative calculations will be presented to NRC staff at a code demonstration meeting at Sandia in Albuquerque.

Deliverable: Code Demonstration Meeting
Completion Date: October 18, 2002

Task 1.2: Crash of Small Plane [redacted] into an ISFSI

Task 1.2A: Planes [redacted] Scenarios

Task 1.2Ai: Survey of Small Planes (6 MWs)

The number of small planes by type in the world air fleet, the carrying capacity (volume) for [redacted] of each type of plane, and the design details (e.g., engine type, number of engines) of each plane type that are significant for the estimation of the effects of a small plane [redacted] sabotage scenario will be determined by literature searches.

Task 1.2Aii: [redacted] that Could Be Used (1 MW)

[redacted] that might be used in a small plane [redacted] sabotage scenario and the pertinent properties of each [redacted] will be tabulated.

Task 1.2Aiii: Crash Scenario Characteristics (3 MWs)

The characteristics (speed, angle of impact, potential for fuel fires, formation of [redacted] from airplane parts) of credible crash scenarios will be tabulated.

Task 1.2Aiv: Representative Scenarios (2 MWs)

The results of Tasks 1.2Ai through 1.2Aiii will be reviewed in order to identify combinations of an aircraft, an [redacted] and a crash scenario that need to be analyzed because they could easily be attempted or, if attempted, could cause great damage. The modeling requirements for each combination will be identified. A representative subset of these combinations will be identified.

Task 1.2Av: Justifications for Neglected Features (1 MW)

Scenario features (e.g., damage due to plane impact, fuel fires [redacted] that need not be modeled will be identified and the reason why they need not be modeled explained.

Task 1.2Avi: Proposed Modeling Methods (2 MWs)

Methods for modeling the representative subset of scenarios of concern will be identified.

Task 1.2Avii: NRC Review Meeting (2 MWs)

The results of Tasks 1.2Ai through 1.2Avi will be presented to NRC at a review meeting.

Deliverable: Review Meeting
Completion Date: June 7, 2002

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Task 1.2B: **Modeling**

For each( ) sabotage scenario (e.g., a( ) scenario) selected by NRC for analysis,( ) damage, fission product release from failed spent fuel rods, fission product transport through the damaged cask to the environment, and accident consequences will be analyzed.

Task 1.2Bi: ( ) **to Casks (11 MWs)**

( ) effects on the HI-STORM storage cask will be examined using the CTH code. Failure of the cask canister and rod failure will be estimated, wherever possible, from predicted canister and rod deformations and( ) PRONTO calculations that use load time histories predicted by CTH will be performed for( ) scenarios where the CTH calculation yields uncertain results concerning cask failure.

Task 1.2Bii: **Fission Product Release to Cask Interior (6 MWs)**

Fission product release fractions from failed spent fuel rods will be estimated using the NUREG/CR-6672 methodology.

Task 1.2Biii: **Fission Product Transport through Cask to Environment (4 MWs)**

The HI-STORM MELCOR input deck for an undamaged cask, developed by NRC project J5160, will be modified to reflect the( ) inflicted on the cask for each( ) sabotage scenario examined. For each of these scenarios, the resulting modified input deck will then be used to perform MELCOR fission product transport calculations for that scenario.

Task 1.2Biv: **Radiological Consequences (2 MWs)**

The radiological consequences that might be caused by each( ) sabotage scenario will be estimated using the MACCS code. Wherever possible, input data developed by Task 1.1E will be used to support the performance of this task.

Task 1.2C: **Report (4 MWs)**

The results of Task 1.2 will be documented in a SAND or a NUREG/CR report.

Deliverable: Task 1.2 Draft Final Report
Completion Date: October 21, 2002

Task 1.3: **Simplified Large Plane Model**

A simplified finite element model of the( ) aircraft and also of the HI-STORM cask will be developed that can be run on a PC using ANSYS/LS-DYNA.

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D. Level of Effort

The following table presents the estimated level of effort and cost for each major task, computer software purchase costs, travel costs (supplies, subcontracts), and total program. The total costs reflect all applicable loads (i.e., the SNL 28 percent load on purchases and subcontracts, the DOE/AL 3 percent added factor).

Task	Title	MWs	Cost ($K)
0	**Program Initiation Meeting**	8	48
1	**Terrorist Events Initiated by Aircraft**		
1.1	Large Jetliner Crash into ISFSI		
1.1A	Mechanical Analysis (ZAPOTEK, CFS, PRONTO)	23	138
1.1B	Thermal Analysis (VULCAN, COYOTE)	27	162
1.1C	Rod-to-Cask Source Terms	4	24
1.1D	Fission Product Transport Through the Failed Cask (MELCOR)	13	78
1.1E	Consequence Calculations (MACCS)	12	72
1.1F/G	Reports	10	60
1.1H	Code Demonstration Meeting	9	54
	Task 1.1 Subtotals	98	588
1.2	Crash of a Small Plane Loaded with [redacted] Ex 2	44	264
1.3	Simplified ANSYS/LS-DNA Large Plane Model	30	180
	Task 1 Totals	172	1032
2	**Weapons, Radioactive Materials, Consequences**	69	414
3	**Models for Other Transportation Casks (NAC-NLI-1/2, NAC-UMS)**	61	366
4	**Models for Other RailCasks (NUHOMS 24P, TN-68)**	61	366
5	**Specified Sabotage Scenarios for RailCasks (per scenario)**	32	192
6	**Specified Sabotage Scenarios for Transportation Casks (per scenario)**	24	144
	Computer Software/Support (ANSYS/LS-DYNA and ANSYS/Mechanical)		90
	Travel (4 four-person Wash DC trips per year @ $1.5K per person per trip)		48
	Program Totals (with all loads)	427	2821

9.0 SUBCONTRACTOR/CONSULTANT INFORMATION

Support from subcontractors or consultants will be needed to support (a) the development of the Source Term Methodology and the sabotage scenarios needed to complete Task 2, (b) the analysis of cask thermal behavior in fires, and (c) to perform consequence calculations.

The members of the expert panel that will develop the Source Term Methodology will be determined by Task 2.2B. R.E. Luna, an transportation risk expert and former manager of SNL's Transportation Technology Program will support the performance of Tasks 1.2 and 2. All analyses of cask thermal behavior will be supported where appropriate by J. A. Koski, a consultant, who for seven years was the technical lead for Sandia's studies of the thermal performance of spent fuel casks. D. I. Chanin, the principal author of the MACCS code and an expert on the costs of

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