3.0 WORK TO BE PERFORMED AND EXPECTED RESULTS

A. Scope of Work

The response of radioactive material (RAM) packages to sabotage attack scenarios and the radiological consequences that these scenarios might cause will be investigated. Sabotage scenarios that involve the deliberate crashing of a jetliner into a RAM package or damage of the package by [redacted] will be modeled using phenomenological codes. The threats posed by other sabotage scenarios will be first assessed by an expert panel; modeling of these scenarios using phenomenological codes will be performed only if the expert assessment identifies questions that can only be resolved by detailed code calculations. Ex 2

Phenomenological modeling of sabotage scenarios will be initiated by modeling the crash of a large jetliner fully loaded with jet fuel into or the [redacted] to a NAC-UMS rail cask and a HI-STORM storage cask. The damage caused to the casks by the impact of the plane, by any ensuing jet fuel pool fire, or by the [redacted] will be calculated. Ex 2

The number of rods in the NAC-UMS or the HI-STORM cask failed by the jetliner impact, by the ensuing fire, and by the [redacted] 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 radiological consequence calculations. These results and results developed by the expert panel will be used to develop simple source term models for spent fuel package sabotage events. Ex 2

Finally, the response to sabotage scenarios of any additional radioactive material packages specified by the NRC will be analyzed, 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 spent fuel transport and storage casks due to jetliner impact will be examined using the CTH and PRONTO codes. CTH is an Eulerian shock code developed at SNL to solve large deformation, strong shock wave, and solid mechanics problems. 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.

The CTH code will be used to predict the global effects of jetliner impact onto a RAM package and the cask damage caused by sabotage scenarios that involve the [redacted] The PRONTO code will be used to examine package damage caused (1) by impact onto a package of the massive hard components (e.g., engine rotor shaft, landing gear strut) of a jetliner and (2) by the impact of one package onto a second package. The CTH and/or SCAP codes will be used to examine sabotage scenarios that involve attacks with HEDDs (e.g., [redacted]) The response Ex 2

Ex 2 portions

of the cask and its fuel rods to fires will be examined using the VULCAN fire code, the CAFE/PThermal fire code, and/or thermal correlations.

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 the number of rods that are failed by the sabotage scenario. The release of fission products from failed rods will then be estimated using MELCOR, a compartment code that implements a full suite of thermal-hydraulic and fission product transport models, or by applying 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 following ten additional packages may be examined by this study: the NAC-NLI-1/2 truck cask, the NUHOMS 32P storage cask, the TN-68 rail/storage cask, the VSC-24 storage 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 calculated using package models initially constructed using SOLIDWORKS.

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 the MELCOR code.. 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 storage site 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 availability of modern parallel processing computers may allow this ambitious schedule to be met.

The impact and [ ] 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 [ ] 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 [ ] 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 Ex 2

Ex 2 portions

Ex 2

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. *The subtask descriptions contained in the initial versions of this proposal (Revisions 0 and 1) have been extensively revised in this proposal revision (Revision 2). This has been done (1) because the task work performed during the first nine months of this program has shown that many subtasks have required much more effort to complete than was initially estimated; (2) because NRC has decided that perhaps one third of the cask/sabotage scenario combinations called out in Revision 1 of this proposal need not be modeled using detailed phenomenological codes, and (3) because a large number of subtasks have been shown to be unnecessary. In this proposal revision, descriptions of unnecessary subtasks have been deleted and the titles of these subtasks have been set flush left and italicized.* Finally, 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 may be somewhat 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: This task has been completed

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] jetliner, and of the hard 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 review meetings and/or conference calls. Ex 2

Ex 2 portions

Task 1.1Ai: Crash of a Large Plane into a HI-STORM Storage Cask (20 MWs)

The crash of a [redacted] into the HI-STORM storage cask will be modeled using the CTH code. 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 cask. The response of the aircraft and the cask developed by these analyses will be used to identify the jetliner crash scenarios that will be examined by Task 1.1Aiii below. Ex 2

Task 1.1Aii: PRONTO Models of the HI-STORM cask, an Aircraft Engine, and an Aircraft Landing Gear (21 MWs)

More detailed PRONTO finite element modelswill be constructed for the Holtec HI-STORM spent fuel storage cask (17 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 (2 MWs) and a [redacted] landing gear (2 MW). 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. Ex 2

Task 1.1Aiii: Detailed PRONTO Jetliner Hard Component Cask Impact Calculations (25 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 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 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.

Because the center fuel tank is being modeled by the CTH global jetliner impact calculations, Task 1.1Aiv may not be necessary.

Task 1.1Aiv: ZAPOTEC Center Fuel Tank Analyses

Task 1.1Av: Analysis of Canister Performance (3 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 impacts. Four possible canister failure modes will be examined: (1) failure due to deformation of the welded 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 PRONTO 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.

Ex. 2 portions

Task 1.1B: **Thermal Analysis**

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 at review meetings and/or during conference calls.

Task 1.1Bi: **Estimation of Amount of Jet Fuel in Fireball and Pool Fire (1MWs)**

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 could 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.

Task 1.1Bii: **Analysis of Canister Response to Fires** (16 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 by an ensuing jet fuel pool fire. The behavior of the canister, when subjected to a fully engulfing, optically dense, jet fuel fire, will be determined by performing canister burst rupture calculations using the JAS 3D and ABACUS codes. 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: **Cask/Canister Response to Pool Fires**

Task 1.1Biii(a): **Undamaged Cask/Canister**

The response of the undamaged HI-STORM cask and canister to jet fuel pool fires will be calculated using the VULCAN code, analytical heat transport correlations, and/or the CAFE/PThermal code.

Task 1.1Biii(a1): **Construct Models** (8 MWs)

Computer models for both the bare canister and the HI-STORM overpack will be constructed for use with the VULCAN and CAFE/PThermal codes. Before being used to perform calculations, all models will be provided to NRC for review and then questions regarding the models discussed at review meetings and/or during conference calls.

Task 1.1Biii(a2): **Run Calculations (14 MWs)**

The models developed by Task 1.1Biii(a1) will be used with the VULCAN and CAFE/PThermal codes to determine the response of the HI-STORM overpack and canister to set fuel pool fires. Two cask orientations, standing and tipped over, and optically dense fully engulfing and partially engulfing pool fires will be examined.

Because Task 1.1A showed that the configuration of the HI-STORM cask is unlikely to be substantially altered by jetliner impact and because Task 1.1Bi concluded that jet fuel pool fires with durations longer than 30 minutes were unlikely, Task 1.1Biii(b) will not be performed.

Task 1.1Biii(b): Damaged Cask/Canister

)additional work on Tasks 1.1C, 1.1Di, and 1.1E has been placed on hold and Task 1.1Dii has not been started. Should PRONTO calculations show that jetliner impact can cause the HI-STORM canister to fail while contained within the HI-STORM overpack, more work may need to be performed on some of these subtasks.

Ex 2

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 cask, 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.

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)

ON-HOLD

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~~

Text not here.

Ex 2 portions

Task 1.1E: **Consequence Calculations (14 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. To support the analysis of sabotage scenarios that involve jet fuel fires, the pool fire plume rise model developed by the Risk Management Department at the Pantex Plant will be implemented in the NRC/SNL MACCS code following the standard QA procedures used to implement changes in that code. Other technical concerns (e.g., near field contamination patterns) 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 at review meetings and/or during conference calls before being undertaken by this task. ON HOLD

Task 1.1F: **Final Report (8 MWs)**

The results of Tasks 1.1A through1.1E will be documented in a Final Report that presents all of the results developed by Task 1.1.

Deliverable: Task 1.1 Draft Final Report
Completion Date: February 28, 2003

Because most of the detailed phenomenological analyses performed in support of Task 1 can only be performed on massively parallel processed computers not available ~~at the NRC,~~ Task 1.1G has been eliminated.

Task 1.1G: Computer Code Demonstration Meeting they can't demonstrate

Task 1.2: **Crash of Small Plane Loaded with ( ) into an ISFSI** Ex 2

Task 1.2A: **Planes( )Scenarios**

Task 1.2Ai: **Survey of Small Planes (4 MWs)**

The number of small planes by type in the world air fleet, the carrying capacity (volume) for ( ) 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 ( ) sabotage scenario will be determined by literature searches. Airplane features (e.g., damage due to plane impact, fuel fires, ( ) that need not be modeled will be identified and the reason why they need not be modeled explained. Ex 2

Deliverable: Letter Report
Completion Date: This task has been completed

Ex 2 portions

Because the damage done by a [redacted] depends almost entirely on the amount of the [redacted] from the target and not on the nature of the vehicle that carries the explosive, Task 1.2Aii through 1.2Avii will not be performed.

Task 1.2Aii: [redacted] that Could Be Used

Task 1.2Aiii: Crash Scenario Characteristics

Task 1.2Aiv: Representative Scenarios

Task 1.2Av: Justifications for Neglected Features (this subtask was transferred to Subtask 1.2Ai)

Task 1.2Avi: Proposed Modeling Methods

Task 1.2Avii: NRC Review Meeting

Task 1.2B: Modeling

For each explosive sabotage scenario selected by NRC for analysis, [redacted] 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: [redacted] Damage to HI-STORM Cask (3 MWs)

[redacted] 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 [redacted] PRONTO calculations that use load time histories predicted by CTH will be performed for [redacted] scenarios where the CTH calculation yields uncertain results concerning cask failure.

Because the [redacted] CTH damage calculations suggest that the HI-STORM cask canister probably [redacted] Tasks 1.2Bii through 1.2Biv have been placed on hold.

Task 1.2Bii: Fission Product Release to Cask Interior

Task 1.2Biii: Fission Product Transport through Cask to Environment

Task 1.2Biv: Radiological Consequences

Task 1.2C: Report (1 MW)

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: March 31, 2003

Portions Ex2

Task	Title	MWs	Schedule: FY02 F M A M J J A S / FY03 O N D J F M A M J J A S / FY04 O N D
0	**Program Initiation Meeting**	8	->
1	**Terrorist Events Initiated by Aircraft**		
1.1	**Large Jetliner Crash into an ISFSI (Hi-Storm cask)**		
1.1A	**Mechanical Analysis**		
1.1Ai	Large Plane Crash into a HI-STORM Cask (CTH)	20	------------------------------------>
1.1Aii	Detailed PRONTO Models		
	Hi-Storm Cask	17	- - - - - - - - - - - ->
	Landing Gear	2	->
	Engine	2	-->
1.1Aiii	Detailed PRONTO Jetliner Hard Component Calculations		
	Landing Gear + Hi-Storm	25	------------------------------->
	Engine + Hi-Storm		
1.1Av	Analysis of Canister Performance	3	--->
1.1B	**Thermal Analysis**		
1.1Bi	Estimation of Amount of Fuel in Fireball and Pool Fire	1	->
1.1Bii	Analysis of Canister Thermal Response to Fires (JAS 3D, ABACUS)	16	----------->
1.1Biii	Cask/Canister Response to Fires (VULCAN, correlations, CAFE-P/Thermal)		
	Undamaged Cask/Canister (w and wo storage overpack)		
	Construct Hi-Storm Cask/Canister Thermal Model	8	----------------------->
	Run Model	14	-------------------->
1.1C	**Rod-to-Cask Source Terms**	4	- - - ->
1.1D	**Fission Product Transport through Hi-Storm cask (MELCOR)**		
1.1Di	Undamaged Cask/Canister	1	--->
1.1E	**Consequence Calculations (MACCS)**	14	---------------------->
1.1F	**Final Report**	8	- - - - - - - ->
1.1G	***Computer Code Demonstration Meeting***		
	Task 0 + Task 1.1 Total MWs	143	
	Task 0 + Task 1.1 $K @ $6.8 K/MW	972	
1.2	**Crash of a Small Plane with [redacted] into a Hi-Storm Cask**		F M A M J J A S O N D J F M A M J J A S O N D
1.2A	**Planes, [redacted] Scenarios**		
1.2Ai	Survey of Small Planes	4	- - - - - - - - - - - ->
1.2B	**Modeling**		
1.2Bi	[redacted] to Hi-Storm cask		
	CTH calcs	3	----------->
	PRONTO calcs		
1.2C	**Hi-Storm Cask Small Plane Crash Report**	1	-->
	Task 1.2 Total MWs	8	
	Task 1.2 $K @ $6.8 K/MW	54	
1.3	**Simplified ANSYS/LS-DYNA Large Plane Model**		
1.3A	**Model Development**		
1.3Ai	Definition of Model Characteristics	3	-------->
1.3Aii	Identification of Modeling Methods	3	------->
	Task 1.3 Total MWs	6	
	Task 1.3 $K @ $6.8 K/MW	41	

Ex 2

D. Level of Effort

The following table presents the estimated level of effort and cost for each major program task, computer software and other purchase costs without the SNL loads on purchases, travel costs without SNL loads, total program costs with all SNL loads but without the 4 percent NISAC load, the cost of the 4 percent NISAC load, and the estimated total program cost with the NISAC load and all SNL loads. Task levels of effort in man-weeks are converted to task costs using an average cost of $6.8 K per man-week over the life of the program.

Task	Title	MWs	Cost ($K)
0	Program Initiation Meeting	8	54
1	Terrorist Events Initiated by Aircraft		
1.1	Large Jetliner Crash into ISFSI		
1.1A	Mechanical Analysis (CTH, PRONTO)	69	470
1.1B	Thermal Analysis (VULCAN, correlations, CAFE/PThermal)	39	265
1.1C	Rod-to-Cask Source Terms	4	27
1.1D	Fission Product Transport Through the Failed Cask (MELCOR)	1	7
1.1E	Consequence Calculations (MACCS)	14	95
1.1F	Report	8	54
	Task 1.1 Subtotal	135	918
1.2	Crash of a Small Plane with [redacted] into a HI-STORM cask	8	54
1.3	Simplified ANSYS/LS-DNA Large Plane Model	6	41
1.4	Large Jetliner Crash into a NAC-UMS Transportation Rail Cask	37	252
1.5	Crash of a Small Plane with [redacted] into a HI-STORM cask	9	61
	Task 1.2 through 1.6 Subtotal	60	408
2	Weapons, Radioactive Materials, Consequences	143	973
3	Models for Other Transportation Casks (NAC-NLI-1/2)	16	109
4	Models for Other Storage Casks (NUHOMS 24P, TN-68, VSC-24)	84	571
5	Specified Sabotage Scenarios for Storage Casks	119	809
6	Specified Sabotage Scenarios for Transportation Casks	13	88
7	Other Radioactive Material Transportation Package Models	13	88
8	Other Radioactive Material Package Sabotage Scenarios	26	177
	Tasks 2-8 Subtotal	414	2815
	Administrative Support		204
	Guidance Document External Review Panel (consultant contracts)		343
	Computer Software/Support (SOLIDWORKS, ANSYS/LS-DYNA ANSYS/Mechanical)		73
	Other Purchases (safe, removable hard drives)		7
	Travel		155
	FY02-FY04 Total MWs and Costs (with all loads)	617	4977

Ex 2 portions