GE Nuclear Energy

General Electric Company
175 Curtner Avenue, San Jose, CA 95125

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U.S. Nuclear Regulatory Commission
Washington DC 20555

Attention: Richard W. Borchardt, Director
Standardization Project Directorate

Subject: **Outstanding Open Items from GIST NRC Meeting**

Reference: "Transmittal of Responses to NRC Questions", December 16, 1993, MFN No. 235-93.

Following the meeting between the NRC and GE on November 18, 1993 regarding the SBWR GIST Test Program, seven open items were identified. In the formal transmittal of the meeting report (Reference), two of the open items were addressed. Attached are the responses to the remaining open items. The previously addressed open items are also identified for completeness. This closes the outstanding issues from that meeting.

Sincerely,

D. C. Leeman for

J. E. Leatherman
SBWR Certification Manager
MC-871, (408) 935-2023

Attachment 1, "Outstanding Open Items from GIST NRC Meeting"

cc: M. Malloy, Project Manager (NRC) (w/2 copies of Attachment 1)
F. W. Hasselberg, Project Manager (NRC) (w/1 copy of Attachment 1)

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NRC GIST Meeting Action Items

Item 1: Prepare an addendum to the scaling report quantifying top down and bottom up parameters. Demonstrate that those parameters GE has identified as not needing to be preserved are small compared to other parameters.

Item 2: Demonstrate that the phenomena identified as "important" in the PIRT analysis are run over the same range of conditions in GIST as expected in the SBWR.

Response to 1 & 2:

Attachment 1 is the requested addendum which addresses the stated issues.

Item 3: Clarify the time at which the line from the suppression pool to the RPV is open.

Response to 3:

This issue was specifically addressed in the "Response to NRC Findings on GIST" (MFN No. 235-93, December 16, 1993).

Item 4 is broken into 2 sub items, 4a and 4b

Item 4a: Document the procedure used in development of the PIRT tables

Response 4a:

The TRACG computer code was qualified for SBWR application using the NRC developed and approved Code Scaling, Applicability and Uncertainty

(CSAU) methodology, References [1] and [2]. The important uncertainties were identified in this four step process:

1. A panel of experts, from both GENE and outside institutions familiar with BWR technology, was convened to generate Phenomenon Identification and Ranking Tables (PIRT). The first step consisted of a brainstorming session, where a list of phenomena affecting BWR transients were generated. At this point the significance of the phenomena were not considered, only whether the phenomena affected BWR transients.

2. At the second step each expert separately and independently generated a ranking of the phenomena based on his or her expectation of their effect on a key result, e.g. Critical Power Ratio change. The ranking was specific to the event type, and to the plant design (i.e., BWR 4/5/6, ABWR and SBWR).

3. These lists were then compared. If the experts agreed on the ranking it was accepted. If the ranking was different, the reasons for the ranking were discussed until a consensus was obtained.

4. As a final validation, the combined table was reviewed by a separate panel of experts, who had not participated in the generation of the tables.

The parameters, which were ranked higher than seven on a scale of one to nine for their influence on the parameter of interest for at least one of the event categories, will be referred to as candidate parameters. Those ranked six or lower are excluded from further consideration. Parameters ranked near this cut-off were preferentially ranked higher than the cutoff, if there was doubt as to their exact importance, so that a quantitative determination of their sensitivity would be made. An independent review was conducted of the ranking by experts who did not participate in the initial ranking.

In addition to model uncertainties, uncertainties in the plant configuration (manufacturing tolerances, instrument uncertainties, operating uncertainties, etc.), which will be referred to as "plant parameter uncertainties" influence the transient response. The plant parameters are considered according to the same CSAU type procedure.

EFFECT OF CANDIDATE PARAMETERS

TRACG was used to determine the effect of the candidate parameters. In cases where it was not practical to vary the parameter through normal inputs, an adjustment factor was provided to perform the sensitivity. In some cases, a separate but related parameter is varied to achieve a desired effect.

For example, the uncertainty in gap conductance is known in terms of its effect on difference between pellet centerline and coolant saturation temperatures. This uncertainty encompasses the uncertainties in the pellet conduction and the pellet radial power distribution. A multiplier is applied to the calculated gap conductance to achieve the desired change in temperature difference.

RELEVANT PARAMETERS

Once the uncertainties in the candidate parameters have been determined the candidate parameters were varied within their 2 sigma uncertainty (or bounding range if applicable) to determine their influence on the parameter of interest.

These calculations were discovered to be biased in two areas. TRACG slightly overproduces the channel void fraction. Therefore a small bias is included in the operating limit determination. The second area of bias is due to uncertainty in the design, versus as-built steamline length. The sensitivity analysis was performed with a shorter than actual steamline length to allow construction flexibility. This has been shown to be conservative for jet pump plants with direct scram on turbine valve closure. However in the course of the sensitivity study it was found that there is a significant positive bias (.072 delta CPR/Initial CPR for the limiting event) due to this design/analysis practice. This bias is included in the operating limit determination and is specific to the SBWR design. An alternative to including this effect as a bias, would be to use the design steamline length (which would increase the reference delta CPR/ Initial CPR) .

Relevant parameters are defined as those candidate parameters which are shown to have a significant effect on the parameter of interest. The candidate parameters are dominated by a small set of relevant parameters, specifically:

The total uncertainty in the application of complex thermal-hydraulic computer codes in advanced reactor transient analysis can be determined using the existing code qualification data base, available test data and plant design specifications, and high speed computers. Quantifying the effect of assumptions and uncertainties yields valuable insight into the plant response for designs which diverge from the current generation of operating plants.

Item 4b: .. with specific emphasis on how it was concluded that phenomena having low or medium importance cannot combine to have a high importance

Response 4b:

This question is related to the basic problem that the CSAU methodology of intends to address. From [2], the following is stated:

> "In developing CSAU, the emphasis was placed on a practical engineering approach that could be used to quantify code uncertainties. Consequently, for a specified Nuclear Power Plant and a given scenario, the CSAU method focuses only on important processes and/or phenomena, assesses the code capability to scale them up, and evaluates the accuracy with which the code calculates them... The ultimate objective of the CSAU process is to provide a simple and direct statement of the calculated uncertainty in the primary safety criteria (e.g. the PCT) used as the basis for assessing safety and making licensing decisions relative to the revised ECCS rule. This objective is accomplished when the magnitudes of individually important contributors are determined, collected, and subsequently combined to provide the desired summary statement. This element contains the activities to calculate, collect, and convince individual contributors to uncertainty into the required total mean and 95% probability statements including separately identified and quantified biases."

The rationale for ranking the phenomena (rather than treating as equally significant is also given in [2]:

> "Plant behavior is not equally influenced by all processes and phenomena that occur during a transient. The most cost-efficient yet sufficient analytical effort reduces all candidate phenomena to a manageable set by identifying and ranking the phenomena with respect to their influence on the primary safety criteria"

A consideration is using a PIRT, and addressing highly ranked phenomena more fully than medium and low ranked ones is therefore, to provide a cost-effective and tractable methodology. GE has considered combinations of only highly ranked parameters, this is consistent with the CSAU methodology of [2]. For example in part 4, "Uncertainty Evaluation of LBLOCA analysis based on TRAC-PF1/Mod 1" of the PIRT parameters, only ten are included in the response surface combinations.

A justification for the process of [2] is reducing the number parameters considered. The CSAU process was developed by the NRC and utilized by GE specifically to address the problem of determining the uncertainty of best estimate codes involved a large number of low, medium and highly ranked uncertainty parameters. This process implicitly answers the question by ranking the parameters, and considering in the sensitivity studies only those highly ranked. In applying the CSAU methodology to TRACG, the medium ranked phenomena were biased to high for conservatism.

The CSAU process is intended to produce a statistically based uncertainty. The confidence level applied is 90 to 95%. While it may be theoretical possible for two parameters to combine non-linearly, it lies outside the probability range that the methodology is intended to address.

REFERENCES

[1] *Quantifying Reactor Safety Margins,* NUREG/CR-5249, EGG-2552, R4.

[2] *Quantifying Reactor Safety Margins,* B.E.Boyack et. al, Nuclear Engineering and Design (Parts 1-4), 119 (1990), Elsevier Science Publishers B.V. (North Holland).

Item 5: Determine and document the potential effect of liquid back flow from the isolation condenser, with specific emphasis on how this system interaction could affect the performance of the depressurization rate.

Response to 5:

This issue was addressed in the "Response to NRC Findings on GIST" (MFN No. 235-93, December 16, 1993).

Item 6: Provide a copy of the GIST RFP and award.

Response to 6:

Attachment 2 is the workscope from the DOE contract for the proposed Gravity-Driven Cooling System test program.

Item 7: Reevaluate the SBWR-GIST Difference Reconciliation, ADS Configuration (reference slide 6 of presentation package on this topic) & inform NRC of results

Response to 7:

Following discussions with Melinda Malloy of the NRC on January 7, 1994, it was determined that Item 7 (which she had added to the action list) was in fact a restatement of the same issue discussed in Item 5 above.

ATTACHMENT 1

Addendum to Scaling Report Quantifying GIST Parameters

SCALING REPORT ADDENDUM
GIST EVALUATION

OBJECTIVE

The objective of this addendum is to provide quantitative assurance that operational information obtained from the GIST test program is representative of the GDCS employed in the SBWR design.

Modeling parameters for heat transfer and fluid flow processes are calculated in order to show that the effects which are important to successful GDCS operation are preserved in the test program. The modeling parameters also provide a basis for determining when an effect or phenomenon introduces a negligible distortion on the GDCS performance, and does not need to be preserved in the scaled GIST system.

BACKGROUND

Scale modeling parameters include: fluid state properties, such as viscosity, density, and surface tension; geometric properties, such as vertical elevation and flow area; fluid flow properties, such as velocity, pressure, and loss coefficients; and energy transfer quantities, such as core decay heat, vessel stored thermal energy, thermal conductivity, and enthalpy. SBWR pressure and temperature were duplicated in GIST to yield identical fluid state properties. GIST vertical dimensions were maintained in a 1:1 ratio with SBWR, whereas horizontal flow areas were in the ratio 1:508 to correspond with the volume scaling ratio. Nondimensional modeling groups are discussed in the following sections, based on 1:1 scaling of fluid state and vertical geometric properties.

ENERGY TRANSFER PARAMETERS

Energy transfer phenomena listed in the SBWR PIRT [5] include fluid mass transfer, core heating, transfer of stored thermal energy in the vessel metal, and void condensation. The importance of these phenomena can be assessed by casting them into the form of the so-called "phase change number" [1],

$$\pi_{pch} = \frac{\dot{Q}^{o}}{\dot{M}^{o}\delta h^{o}}$$

where

$\dot{Q}^o$ = Equivalent heat transfer rate of process

$\dot{M}^o$ = GDCS flow rate, 125 kg/s (2000 gpm) which corresponds to the bounding analysis for a GDCS line break, reported in the SSAR [2].

$\delta h^o = h_{fg}$ = vaporization enthalpy, 2258 kJ/kg at one atmosphere pressure [3]

When $\pi_{pch} << 1.0$, the process being considered exerts an insignificant effect on the overall GDCS operation, and does not need to be preserved in GIST.

The phase change number is next evaluated for various energy transfers that would occur during operation of the GDCS.

CORE DECAY HEAT

A core decay heat fraction of 0.023 at 500 s GDCS flow initiation [4] yields

$$\dot{Q}^o = (0.023)(2000)\text{MW} = 46\ \text{MW}$$

which is incorporated in the phase change number to give

$$\pi_{phc} = 0.16 \quad \text{core decay heat}$$

Since π_{pch} for decay heat is near a first order magnitude, it is necessary to preserve the core decay heat process in GIST.

VESSEL HEAT LOSSES TO SURROUNDINGS

It has been determined that vessel heat losses to the surroundings are dominated by the insulation conductivity. This is supported by the overall heat transfer coefficient of 0.2 Btu/h-ft^2-F , whereas the insulation conduction parameter is k/d = 0.25 Btu/h-ft^2-F [5]. Even if the insulation were absent, the estimated free convection heat transfer coefficient on the vessel outer surface is 1.0 Btu/h-ft^2-F . For the insulated case,

$$\dot{Q}^o = \frac{k}{d} A \delta T = 5000\ \text{kW}$$

and the corresponding phase change number is

$$\pi_{pch} = 0.018 \quad \text{vessel heat loss, surroundings}$$

Since π_{pch} is much less than 1.0, it is concluded that vessel heat losses to the surroundings do not need to be preserved in the GIST facility.

STORED THERMAL ENERGY IN RPV AND INTERNALS

The decreasing fluid temperature in the vessel during blowdown decompression causes heat transfer from the heated vessel walls and internal mechanical components. This release of stored energy will cause additional vapor generation, thus reducing the vessel inventory. The rate of heat transfer from the vessel and internals, relative to the GDCS energy introduction is needed in order to determine if this effect must be preserved in GIST.

The RPV and internals metal mass, specific heat, and a nominal temperature difference between the metal and fluid, are

$M_m = 1.6 \times 10^6$ lbm approximate metal mass [6]

$A = 97{,}000$ ft^2 approximate metal area [6]

$c_v = 0.11$ Btu/lbm-F metal specific heat [7]

$\delta T = 542 - 212 = 330$ F nominal temperature diff.

The resulting stored thermal energy in the metal is

$$E_m = M_m c_v \delta T = 5.8 \times 10^7 \text{ Btu} \quad (61{,}000 \text{ MJ})$$

An estimate is needed for the rate at which the stored thermal energy can be transferred to the vessel fluid.

If the heat transfer is limited by boiling convection on the metal surfaces, a nominal convective heat transfer coefficient is about $h = 5000$ B/h-ft^2-F , for which the initial heat transfer rate would be about

$$\dot{Q}_{cL} \approx hA\delta T = 4.7 \times 10^7 \text{ Btu/s} \quad (50{,}000 \text{ MW})$$

However, if the metal heat transfer is limited by conduction through the metal to the surface, the conduction response time is given by [7]

$$\delta t \approx \frac{4L^2}{\alpha}$$

where L is the average metal thickness and α is the metal thermal diffusivity. For an example case in which

$$L = 0.1 \text{ ft} \quad , \quad \alpha = 0.15 \text{ ft}^2/\text{h} \text{ [7]}$$

it follows that

$$\dot{Q}_{cond} = \frac{E_m}{\delta t} = 64 \text{ MW}$$

The actual heat transfer rate cannot exceed the slower of surface convection or internal conduction, and for these parameters, it is limited by conduction. Therefore, the phase change number for RPV and internals heat transfer is

$$\pi_{pch} = 0.23$$

This shows that it is necessary to preserve the transfer of RPV and internals stored (sensible) heat in GIST.

Because of the inability to preserve the vessel thickness and surface areas of the RPV and internal components, heat transfer to the vessel fluid in GIST will be faster than in the full size SBWR. This phenomenon results in a quicker release of thermal energy from the metal mass, which in turn, results in the metal mass temperature remaining close to the fluid temperature during the blowdown. During blowdown in SBWR, the higher metal temperature will cause continued voiding in vessel regions below the core. In GIST, where the quicker release of metal energy resulted in nearly equal metal and fluid temperatures, voiding in the vessel outside the core stopped when the vessel depressurization rate approached zero. This resulted in a lower two-phase level, which was accomodated by adding water in GIST prior to blowdown in order to achieve the two-phase level expected at the end of blowdown.

CRD FLOW AND VOID COLLAPSE

In order to determine the importance of CRD flow on void collapse, the maximum condensation heat transfer rate of CRD flow is first estimated. The CRD mass flow rate m_{crd} undergoes an enthalpy change of $h_f - h_{crd}$ from its incoming value to that of saturated water. Simultaneously, the condensation rate m_g changes from saturated vapor to saturated liquid, an enthalpy change of h_{fg}. Therefore, the equivalent heat transfer rate for condensing voids is

$$\dot{Q}_{crd} = m_g h_{fg} = m_{crd}(h_f - h_{crd})$$

A CRD mass flow rate of 63 lbm/s (460 gpm) **[2]** and enthalpies of $h_f = 180$ and $h_{crd} = 60$ Btu/lbm **[3]** yields

$$\dot{Q}_{crd} = 8000 \text{ kW}$$

for a phase change number of

$$\pi_{pch} = 0.03$$

It is therefore not necessary to preserve the CRD flow in the GIST facility for GDCS simulation. However, a scaled CRD flow, corresponding to 160 gpm in SBWR **[8]**, was tested in GIST, and found to be insignificant **[4]**.

PRESSURE AND FLOW DISTURBANCES

The GDCS flow rate is sensitive to the pressure existing at both the pool surface and in the RPV at the position where it enters. Several phenomena can occur which may create local pressure disturbances in the RPV, altering the GDCS flow rate. These phenomena include addition of the core decay heat and associated void formation, which may take the form of geysering or percolating. It is desirable to estimate the associated pressure disturbance, and its effect on the GDCS flow rate.

PRESSURE DISTURBANCE FROM FLASHING/GEYSERING

The core fluid volume V is given by the core height H and the fluid area A, for which

$$V = HA$$

The mass of water expelled from the core when it flashes is given by

$$M = \frac{V}{v_{fg}}$$

Core decay heat at a rate $\dot{Q}_d$ can vaporize the water mass M in a time interval given by

$$\delta t \approx \frac{h_{fg} M}{\dot{Q}_d} = \frac{h_{fg} V}{\dot{Q}_d v_{fg}}$$

For the parameters [6],

$$v_{fg} = 1.69 \ m^3/kg \ , \ @ \text{ one atmosphere}$$

$$H = 9 \text{ ft}$$

$$A = 84 \text{ ft}^2$$

$$\dot{Q}_d = 46 \text{ MW}$$

with v_{fg} = 1.69 m3/kg [3], the time to form a core volume of steam is

$$\delta t \approx 0.6 \text{ s}$$

The corresponding water acceleration is estimated from lifting a water comlumn of height H out of the core in the time interval $\delta t = 0.6$ s, for which

$$a \approx \frac{H}{\delta t^2} = 23 \text{ ft/s}^2$$

Therefore, the acceleration for flashing-related processes in the core could be approximately 23/32.2 , or about 70% of the acceleration of gravity. The corresponding pressure disturbance is estimated from

$$\delta P \approx \frac{M}{g_o A} a = \rho_f H \frac{g}{g_o} \frac{a}{g} \approx 2.7 \text{ psi}$$

The effect of a 2.7 psi pressure disturbance on the GDCS flow rate is considered next.

EFFECT OF PRESSURE DISTURBANCE ON GDCS FLOW RATE

The volume flow rate Q between the pool and RPV is obtained from the steady flow energy equation, giving

$$Q = A\sqrt{\frac{2g(L+H) + \dfrac{2g_o(P_p - P_r)}{\rho}}{\Sigma K + 1 + \dfrac{fL}{D}}}$$

where L is the vertical piping length, H is the pool depth, P_p is the pool surface pressure, P_r is pressure in the RPV at the GDCS inlet, K is a typical loss coefficient in the GDCS flow path, f is the pipe friction factor, D is the pipe diameter, and A is the piping flow area. Writing the differential of Q for a disturbance in pressure, the fractional flow rate disturbance is given by

$$\frac{\delta Q}{Q} = \frac{\delta(P_p - P_r)}{2[(\rho_f g/g_o)(L+H) + (P_p - P_r)]}$$

For a case in which the pool and RPV pressures are initially equal, a pressure disturbance of the amount

$$\delta(P_p - P_r) = 2.7 \text{ psi}$$

at the GDCS inlet to the vessel, and a total water head of

$$L + H = 37 \text{ ft}$$

the estimated flow rate disturbance fraction is

$$\frac{\delta Q}{Q} = 0.1$$

It follows that rapid vaporization/geysering-type disturbances in the RPV can have up to a 10 percent effect on the GDCS flow rate. The range of flow rates obtained in GIST by employing from one to four flow tubes far exceeds the flow rate distortions which might be caused by vaporization disturbances in the RPV.

Vaporization disturbances are more likely to occur in the GIST facility because of the larger heat transfer surface/volume ratio. However, the overall effect of GDCS flow rate is seen to be only about 10 percent.

GIST FLOW REQUIREMENT

One more feature of the GIST facility is that it provides up to four tubes for the GDCS flow to enter the vessel. The total GDCS flow was a test parameter. Various tests had one to four tubes open for GDCS flow in order to ensure that the simulated range was broad enough to evaluate various flow ranges in SBWR.

The current SBWR design analyses of the main steam line break DBA show a quasi-steady GDCS flow of [2]

$$Q_{dba} = 2000 \text{ gpm } (125 \text{ kg/s})$$

The corresponding GIST flow, for a volume scaling factor of 1/508, would be

$$Q_{gist} = \frac{2000}{508} = 3.9 \text{ gpm}$$

Gravity flow through a single tube in the GIST facility was measured as 1.3 gpm. Total flow rate through four simultaneous tube flows was 4 x 1.3 = 5.2 gpm. It is seen that the flow rates achieved in GIST for one, two, three, and four tubes flowing widely bounded the 3.9 gpm flow, which would simulate the SBWR 2000 gpm GDCS flow rate.

REFERENCES

1. G. Yadigaroglu, "Scaling of the SBWR Related Tests," NEDC-32288, Rev. 0, Class 2, Nov. 1993.

2. SBWR Standard Safety Analysis Report, 25A5113

3. NBS/NRC Steam Tables, Hemisphere, 1984.

4. P. Billig, "Advanced Light Water Reactor Plants," GEFR-00850, Class 2, October 1989.

5. "Response to NRC Findings on GIST," MFN No. 235-93, December 16, 1993.

6. "GDCS Test Program, Test Requirements and Test Specifications for GDCS Integrated Systems Test," WA No. XVS841875, Rev. 1, October 30, 1987.

7. F. Kreith, Principles of Heat Transfer, 3rd Ed., IEP--A Dun-Donnelley Publisher, 1976.

8. J. Mross, "Final Test Report, Testing of the Gravity-Driven Cooling System for the Simplified Boiling Water Reactor," NEDO-31680, July, 1989.

ATTACHMENT 2

Workscope from DOE Contract Applicable to GIST Program

2. <u>GRAVITY-DRIVEN COOLING SYSTEM</u>

TASK 1 - <u>Code Revisions</u>

<u>Description of Work</u> - Modifications to Contractor proprietary computer programs to incorporate two-phase flow data, core and containment physical features and properties, and thermal-hydraulic phenomena applicable to reactor blowdowns down to low-pressure conditions to improve the accuracy necessary for this reactor type and this type of analysis. Develop software engineering procedures, documentation, review, and disciplines appropriate to maintain code credentials for use in actual MBWR licensing activities. Includes revisions to the computer code user's manual, and to the code Technical Description documentation.

TASK 2 - <u>Test Planning</u>

<u>Description of Work</u> - Define facility and testing needed to qualify blowdown model and computer codes, including test variables that must be measured and analyzed. Define computer code qualification strategy, procedure. Produce Test Requirements and Test Specifications document. Produce Test Plan and Procedure document, QA Plan, and Software/Data Reduction Specification. Produce coding/setup of data reduction programs. Perform pre-test predictions of selected transients, using modified computer codes in their form following completion of Task (1) above.

TASK 3 - <u>Facility Modification</u>

<u>Description of Work</u>

- Test Sections/Devices Design and Construction -- Modifications to internals of FIST to represent MBWR as required for gravity-driven cooling ECCS flow injection into reactor; flow paths of GDCS flow into above-core, below-core regions. Design and fabrication of FIST fuel assembly.

- Facility Modifications/Construction -- Design and construction of improvements and upgrades needed to position suppression pool tankage at appropriate elevations relative to core; seismic review/upgrade of structure; addition of weather enclosures, stairways, platforms, ladders, etc., to enable safety and convenient working conditions; extensions of air, water, electrical services.

- Facility Operational Controls -- Modifications as needed to conduct and control MBWR-simulated LOCAs and to set up test conditions.

- Instrumentation Procurement and Hookup -- Purchasing of instrumentation to control, monitor, and record test initial and transient conditions; test instrumentation installation, debug, connection to (existent) FIST Data Acquisition System.
- Special Operator Training -- Develop procedures and provide training for current operators to reflect latest fire protection, safety hazards, OSHA compliance resulting from facility modifications.
- Test Equipment Assembly ad Checkout -- Assure facility operational capability via appropriate pre-op, startup, checkout runs.

TASK 4 - Conduct Test Program

Description of Work - Conduct test blowdowns as specified by test matrix. Includes all instrumentation and DAS preparation, calibration, post-test calibration as required; completion of detailed test logs, certifications as required. Process DAS-captured signals through data reduction software from Task (2), above; produce comprehensive transient results plots. Perform results analyses and evaluations as specified by Test Plan and Procedure documents. Incorporate appropriate results into computer codes. Provide proof runs of computer codes produced by Task (1). The Government shall restore test facility to its previous condition unless deemed unnecessary by mutual agreement of the Government and Contractor.