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1. PURPOSE

The purpose of this document is to identify and analyze concepts for the acquisition of data in support of the Performance Confirmation (PC) program at the potential subsurface nuclear waste repository at Yucca Mountain, and to describe a system for the Viability Assessment (VA) design.

This analysis is being prepared to document an investigation of design concepts and technical issues associated with data acquisition during the Performance Confirmation period. This analysis utilizes the *Performance Confirmation Concepts Study Report* (PCCSR) prepared in November, 1996, as its starting point (Reference 5.5). The focus of this analysis is primarily on the period after the start of waste package emplacement and before permanent closure of the repository, a period lasting approximately 125 years.

The scope and primary objectives of this analysis are to:

- Review the key parameters for design as presented in Appendix D of the *Performance Confirmation Concepts Study Report*. The scope of this analysis will be limited to the data acquisition system regarding the parameters which require continuous or temporary in-drift monitoring of the conditions underground. Acquiring data from mapping, sample recovery, laboratory analysis, and waste package recovery are considered outside the scope of this analysis.
- Identify and evaluate the monitoring alternatives during performance confirmation to acquire data regarding key repository design parameters. This analysis will examine concepts related to exhaust air monitoring, observation and perimeter drift borehole monitoring, and in-situ monitoring within the emplacement drifts.
- Develop a design concept for accommodating in-drift observations via the use of a remotely controlled system. Discuss reasonably available technologies and provide general equipment descriptions. Discuss aspects of equipment reliability and maintenance. Evaluate technologies used for emplacement for possible use in performance confirmation design activities.
- Based on performance confirmation monitoring needs and available technologies, develop a potential data acquisition network in support of the performance confirmation program and describe a system for Viability Assessment (VA) design.

This analysis is being performed early in the systems' engineering cycle, even as issues and requirements related to the performance confirmation program are being formulated and while the associated needs, constraints and objectives are yet to be fully defined. This analysis is primarily

concerned with identification and description of key issues related to the data acquisition system during performance confirmation. This analysis can be used to guide future concept development and help assess what is feasible and achievable by application of data acquisition technology. Future design and systems engineering analysis with applicable iterations of modeling, optimizing, ranking and refinement of concepts will be needed to arrive at optimal design concepts.

2. QUALITY ASSURANCE

Performance Confirmation (PC) design activities were evaluated per Quality Administrative Procedure QAP-2-0. The evaluation was documented on administrative form number 0565 and reached the conclusion that this analysis should be subject to the QARD (Reference 5.2) for the following reasons:

1. The activity affects an item on the MGDS Q-List (Reference 5.20),
2. The activity supports performance confirmation, and
3. The activity could adversely impact the waste isolation function.

Therefore, this analysis is prepared per QAP-3-9.

A QAP-2-3 classification analysis for the items affected by PC activities has not been performed. QA controls will be developed for the PC program in the future and are not within the scope of this analysis.

Much of the input data used in this analysis is preliminary and unqualified and, therefore, the outputs are also unqualified. Because of the preliminary nature of this analysis, the unqualified data is not identified and the formal TBV and TBD tracking system described in NLP-3-15 *To Be Verified (TBV) And To Be Determined (TBD) Monitoring System* is not applied. The output from this design analysis will not be used for procurement, fabrication, or construction without identifying the unqualified data as TBV.

3. METHOD

This analysis is an initial effort to examine issues and develop concepts related to the use of data acquisition and remote monitoring technologies for obtaining data in support of the performance confirmation program. As such, the methodology of this analysis combines systems engineering approaches that include normative synthesis (a study of input documents for objectives and policies that are seen as desirable to the attainment of the objective), descriptive identification of existing systems and technologies, and scenario writing to aid in the formulation, discussion and preliminary

analysis of key issues and ideas related to monitoring the repository performance. The general approach in developing this analysis is to: a) identify and review the key design input source documents, b) perform preliminary analyses and design activities, and c) summarize key findings and recommendations.

4. DESIGN INPUTS

The primary source documents for input information utilized in this analysis are the Repository Design Requirements Document (RDRD) (Reference 5.3), the Controlled Design Assumptions (CDA) (Reference 5.4), and the Mined Geologic Disposal System (MGDS) Advanced Conceptual Design (ACD) Report (Reference 5.10).

This analysis is an early effort in the area of developing data acquisition concepts for Performance Confirmation; as such, it also uses information available in published reports, technical papers and vendor publications. As indicated in QAP-3-9, these resources can be used in the formulation of the analysis since they are referenced in the reference section (Section 5) of this analysis.

4.1 DESIGN PARAMETERS

This section contains engineering values that are used in repository concept development and design.

4.1.1 Radiation Shielding Design Parameter: Pressurized Water Reactor (PWR) Spent Fuel Neutron Source Data

For commercial PWR spent nuclear fuel (SNF), the neutron source strength is taken directly from the Characteristics Data Base (CDB) (Reference 5.30). Since the neutron source spectrum is unavailable in the CDB, the neutron spectral data provided in the GA-4 spent fuel transportation cask design (Reference 5.31) are used for this design analysis. The following neutron source data are used in this analysis:

Neutron Source Strength (Reference 5.30, computer output)

PWR Fuel: 6.740E+8 n/s per MTU (neutrons per second per Metric Tons of Uranium)

Neutron Source Spectrum for PWR Fuel (Reference 5.31, p 5.2-6)

<u>Energy (MeV)</u>	<u>Unnormalized Spectrum</u>
6.43-20.0	2.345E+5
3.00-6.43	2.691E+6
1.85-3.00	3.002E+6
1.40-1.85	1.680E+6
0.90-1.40	2.265E+6
0.40-0.90	2.466E+6
0.10-0.40	4.827E+5
0.00-0.10	0.0
<hr/>	
Total	1.282E+7

4.1.2 Radiation Shielding Design Parameter: PWR Spent Fuel Gamma Source Data

As for the neutron source data, the gamma source strength for the active fuel regions of commercial PWR spent fuel assemblies is obtained from the CDB. Rationale: the source terms for waste packages and spent fuel canisters fully loaded with fuel assemblies is based on the thermal/shielding Design Basis Fuels (DBF) defined in the ACD report (Reference 5.10, Vol III). For PWR fuel assemblies, the DBFs have the characteristics of 4.2 % initial enrichment, 48086 MWD/MTU burnup and 10 years decay, which would bound 97.85% of PWR fuel expected to be received at the MGDS, based on the "oldest-fuel-first" scenario. The CDB also provides the gamma source energy spectrum required for this design analysis as shown below:

PWR Fuel Gamma Source Data (Data and footnote reproduced directly from Reference 5.30, computer output)

Light Water Reactor (LWR) Radiological DATABASE

PHOTONS REPORT

REACTOR TYPE & BURNUP: PWR 48086 MWD/MTU

(Where MWD means Megawatt-days, and MTU stands for Metric Tons of Uranium)

ENRICHMENT: 4.20%

DECAY TIME: 10 YEARS

The data is shown in Photons per second/MTIHM (metric ton initial heavy metal)

ENERGY (MeV)	PHO/SEC	% TOTAL
1.000E-02	2.728E+15	24.27%
2.500E-02	5.787E+14	5.15%
3.750E-02	7.125E+14	6.34%
5.750E-02	5.396E+14	4.80%
8.500E-02	3.229E+14	2.87%
1.250E-01	3.145E+14	2.80%
2.250E-01	2.640E+14	2.35%
3.750E-01	1.257E+14	1.12%
5.750E-01	4.798E+15	42.69%
8.500E-01	4.671E+14	4.16%
1.250E+00	3.849E+14	3.42%
1.750E+00	4.879E+12	0.04%
2.250E+00	7.693E+10	0.00%
2.750E+00	5.940E+09	0.00%
3.500E+00	7.264E+08	0.00%
5.000E+00	2.900E+07	0.00%
7.000E+00	3.343E+06	0.00%
9.500E+00	3.841E+05	0.00%
TOTAL	*1.124E+16	100.01%*

*[Note: the following statement is a quotation from the reference associated with the data cited above] "This value was obtained by interpolating TOTALS values from ORIGEN2 runs to the specific burnup/enrichment/age combination you specified. Percentages have been calculated from this interpolated value and may not add up to 100 percent in all cases."

4.1.3 Material Data for Radiation Shielding Analysis

The following material data are obtained from Reference 5.35:

Alloy 825 for waste package inner barrier (density = 8.14 g/cc) (Reference 5.35, p I-2)

<u>Element</u>	<u>Weight %</u>
C	0.0500
Al	0.2000
Si	0.5000
S	0.0300
Ti	0.9000
Cr	21.500
Mn	1.0000
Fe	28.570
Ni	42.000
Cu	2.2500
Mo	3.0000

Grade 55 A 516 carbon steel for waste package outer barrier (density = 7.832 g/cc) (Reference 5.35, p I-1)

<u>Element</u>	<u>Weight %</u>
C	0.2200
Si	0.2750
P	0.0350
S	0.0350
Mn	0.9000
Fe	98.535

SS316B6A borated stainless steel with 20% boron removed (density = 7.745 g/cc) (Reference 5.35, p I-12)

<u>Element</u>	<u>Weight %</u>
B-10	0.2311
B-11	1.0530
C	0.0301
N	0.1003
Si	0.7524
P	0.0451
S	0.0301
Cr	19.061
Mn	2.0064
Fe	60.639
Ni	13.5433
Mo	2.5080

SS304 stainless steel (density = 7.9 g/cc) (Reference 5.35, p I-4)

<u>Element</u>	<u>Weight %</u>
C	0.0800
N	0.1000
Si	0.7500
P	0.0450
S	0.0300
Cr	19.000
Mn	2.0000
Fe	68.745
Ni	9.250

Air (density = 0.001225 g/cc) (Reference 5.35, p I-19)

<u>Element</u>	<u>Weight %</u>
N	80.000
O	20.000

Tuff medium for emplacement drift wall (dry bulk density = 2.22 g/cc) (Reference 5.35, p 27)

<u>Compound</u>	<u>Weight %</u>
SiO ₂	78.900
Al ₂ O ₃	12.300
Fe ₂ O ₃	0.973
CaO	0.451
MgO	0.128
TiO ₂	0.092
Na ₂ O	3.920
K ₂ O	3.180
P ₂ O ₅	0.010
MnO	0.046

4.1.4 Fiber optic data transmission rate = 150 million bits per sec (Mbps) (Reference 5.17)

4.2 CRITERIA

The following design criteria were developed to respond to RDRD (Reference 5.3) requirements that specifically apply to this design analysis. RDRD requirements are cited for each criteria statement.

- 4.2.1 Provide a preliminary basis for developing data acquisition system (DAS) concepts which can be used to support performance confirmation tests that are determined necessary by the U.S. Department of Energy (DOE). These include tests of the nuclear waste, tests of the geologic repository including its SSCs, tests of radiation detection instruments, and tests of equipment and devices used in connection with the receipt, handling and storage of radioactive waste. (RDRD 3.7.6.A.1 and 3.7.6.A.3)
- 4.2.2 Develop and examine alternative preliminary design concepts for acquiring performance confirmation data that will indicate whether actual underground conditions are within the limits assumed in licensing. These concepts are to support the capability of obtaining information indicating whether natural and engineered barriers are functioning as originally intended and that these systems will continue to function properly after permanent closure of the repository. The concepts are also to support a means for detecting whether components required for repository operation are functioning as intended and anticipated. (RDRD 3.7.6.A.4, 3.7.6.A.4.a and b)

- 4.2.3** Examine DAS concepts and issues related to performing in situ monitoring and in situ experiments needed to accomplish the performance confirmation program objectives. (RDRD 3.7.6.A.5 and 3.7.6.D)
- 4.2.4** Develop a preliminary DAS which can be used to support post-emplacement in-drift performance confirmation tests such as measuring rock deformations and displacements, changes in rock stress and strain, rate and location of water inflow into underground areas, rock pore water pressures, including those along fractures and joints, and the thermal and thermomechanical response of the rock mass as a result of development and operations of the geologic repository. (RDRD 3.7.6.C)
- 4.2.5** The design and implementation of remote control systems for performance confirmation operations will limit radiation exposure to humans and promote as low as is reasonably achievable (ALARA) guidelines for occupational doses. (RDRD 3.2.2.1.A, 3.2.2.1.B, 3.2.4.5.2)
- 4.2.6** The remote control system will be designed with redundant features and self-diagnostic capabilities so that overall reliability of the system will meet critical repository requirements. (RDRD 3.2.5.1, 3.2.5.1.5, 3.3.6.3.F, 3.5.1.1.1.C)
- 4.2.7** Radiation monitoring equipment and alarm systems will be installed in all restricted and unrestricted areas of the underground repository. (RDRD 3.2.2.4, 3.2.2.4.B, 3.2.2.4.B.1, 3.2.2.4.B.2, 3.2.2.4.C, 3.2.4.3.2.B.1.b, 3.2.4.4, 3.7.3.7.I, 3.7.6.A.1.c, 3.7.7.A.6, 3.7.7.E)
- 4.2.8** The DAS will be designed to be maintainable and have a 100 year service life. (RDRD 3.2.5.2.6, 3.2.5.2.8.B, D and E, 3.2.5.4.A, 3.5.1, 3.5.1.1.1A thru E)

4.3 ASSUMPTIONS

4.3.1 General Assumptions from the CDA

The following section contains relevant excerpts from the Controlled Design Assumptions (CDA) Document (Reference 5.4) that relate to the use and deployment of possible remote control equipment. Rationale for these assumptions are cited in Reference 5.4. All controlled assumptions will require substantiation as discussed in Section 2.3 of the CDA. (Used Throughout)

Key 011: Waste packages will be emplaced in-drift in a horizontal mode.

- Key 013:** No human entry is planned in emplacement drifts while waste packages are present. The waste emplacement/retrieval equipment may use robotics and/or remote control features to perform operations and monitoring within the emplacement drifts. Under off-normal conditions, human entry will be considered if protection to the workers can be provided.
- Key 016:** The repository will be designed for a retrievability period of up to 100 years after initiation of emplacement.
- Key 030:** Rail will be used for transporting supplies and personnel underground to the extent practical.
- Key 061:**
1. Repository design and operation shall provide facilities, access, instrumentation, recording, maintenance and support for measuring/monitoring the performance confirmation parameters identified in Appendix D of the FY 96 *Performance Confirmation Concept Study Report*.
 2. The performance confirmation monitoring and measuring system shall have a maintainable service life of 125 years (100 years plus the duration of initial construction plus the duration of final closure plus any time period during site characterization for which the system must be operable). Specific equipment and components shall have maintainable service lives dependent upon their identified function. These service lives are to be determined (TBD).
 3. Planning of repository design and operations for performance confirmation test facilities and support shall consider the performance confirmation concepts identified in Section 5 of the *Performance Confirmation Concept Study Report* as a point of departure.
 5. Test locations/environments, samples, and specimens, onsite and offsite shall be representative of the Repository environments and design elements.
 6. Performance confirmation staff, measurement and monitoring hardware and software, shall be available to support the variable demand for analysis, assessment, and periodic reporting throughout the Performance Confirmation Program.

8. At least one alcove shall be provided for testing and monitoring the Ghost Dance Fault prior to and following emplacement.
9. Monitoring of at least two percent of the thermal rock mass behavior (to be related to the number of emplacement drifts) shall be performed; a portion of the rock mass to be monitored should be near the first emplacement drifts to contain waste.
10. The Repository Subsurface Facilities shall provide underground openings (drifts, alcoves, boreholes, and ancillary excavations), access, data acquisition, and test support to implement performance confirmation monitoring and test recommendations including interface and coordination with Site Investigation Testing, Repository Testing, Waste Package Testing, and Surface Support. These operations are to include, but are not to be limited to, capabilities for:
 - c. Placement and recovery of material coupons or specimens in the emplacement drift or other underground locations shall be performed at least once every 10 years.
 - e. The design, excavation, and ground support of emplacement drifts shall permit installation of and access to test/monitoring instrumentation, and observation drift instrumentation, and provide access for remotely operated vehicles or mobile inspection platforms to obtain measurements.
 - f. Excavation of at least one permanent observation drift above the repository horizon shall be developed in support of thermal monitoring.
 - h. The air temperature, relative humidity, and gaseous radioactive emissions of all emplacement drifts shall be monitored through the drift ventilation.
 - i. The ventilation monitoring system shall be capable of identifying the specific drifts that are the sources of gaseous radioactive emissions, if any, within TBD hours of detection of such emission.
 - j. The provision and use of remotely operated vehicles or movable inspection platform for monitoring emplacement drift environments

and effects shall be considered in support of the following requirements:

- Personnel access into emplacement drifts shall not be permitted except for emergencies.
- Remote inspections of emplacement drifts at least once every ten years shall be performed to monitor rockfall, and visually inspect and thermally image waste packages.

Key 066: Waste packages will be placed center in-drift, on pedestals, using gantry emplacement.

EBDRD 3.7.1.J.1 The external dimensions of the waste package for a) commercial SNF that is repackaged and for b) uncanistered commercial SNF shall not exceed:

Outer Diameter: 1850 mm

Outer Length: 5850 mm

DCSS 019 Maximum Underground Air Temperature - Emplacement Drifts

Maximum allowable air temperature in emplacement drifts during:

Caretaker: no limit, determined by rock temperature

Retrieval: 50°C dry-bulb, only in portion requiring access

DCSS 023 Maximum Preclosure Rock Surface Temperature

Maximum allowable Preclosure rock surface temperature in:

Shafts: 35°C -unventilated

Ramps: 35°C -unventilated

Mains: 50°C

Emplacement Drifts: 200°C

Temporary increases in these temperatures are allowed during initial cooling of emplacement drifts for maintenance, performance confirmation, retrieval and backfilling.

DCSS 028 Emplacement Drift, Shafts, Ramps Maintenance Plans

Emplacement drifts will be designed to be stable through the caretaker period, with the goal to minimize or eliminate planned maintenance to sustain the ability to retrieve, sample, or relocate waste packages. Shafts, ramps, and all other drifts will be designed to be stable, but may rely on periodic planned maintenance.

DCSS 029 Maximum Underground Air Temperatures - Exhaust Mains

Maximum allowable air temperature in exhaust mains during:

Caretaker: 50°C dry-bulb

Retrieval: ≤ emplacement drift rock surface temperature

DCWP 005 The external dimensions of the waste package containing DOE SNF that is co-disposed with defense HLW shall not exceed:

Outer Diameter: 1970 mm

Outer Length: 5350 mm

4.3.1.1 The total number of emplacement drifts used in this analysis is 159. This quantity is based upon Figure 3.2 of Key 072 of the CDA. A different total quantity of emplacement drifts will not invalidate the concepts developed in this analysis. (This assumption is used in section 7.4.4.)

4.3.2 Specific Assumptions for this Analysis

4.3.2.1 The maximum length of the emplacement drifts will be approximately 600 meters. Rationale: as indicated in Reference 5.10, pg 8-75. (Used in Attachment I)

4.3.2.2 Current design assumptions for the subsurface repository are based on the emplacement drift bore diameter of 5.5 meters. The emplacement drifts may be lined with pre-cast concrete liners up to 200 mm thick. This will reduce the useful inner diameter to approximately 5.1 meters (Reference 5.26). (Used in Sections 7.6.2, 7.6.6, 7.6.7, and Attachments II & IV)

4.3.2.3 The allowable air temperature for equipment and data acquisition systems in an observation drift is taken to be 50°C, based on the maximum assumed for the operation of emplacement equipment (CDA assumption DCSS 019). For periodic entry to an

observation drift by personnel, a limit of 27°C (effective) air temperature is assumed (CDA assumption DCSS 019) (Reference 5.4) (This assumption is used in Section 7.7.2).

- 4.3.2.4** During the course of repository operations, there will be a turnover sequence in which groups of drifts will be removed from the development (construction) side of the repository and placed on the emplacement side of the repository as the repository is constructed. This analysis will use thirteen as the number of drifts which will be turned over in each group from the development side to the emplacement side of the repository. This assumption is based on the current repository construction concept (Reference 5.10 Vol II, pg 8-139 & 8-141). (This assumption is used in section 7.4.4)
- 4.3.2.5** The distance between the centerlines of the emplacement drifts used in this analysis is 22.5 meters. This drift spacing is based on the horizontal in-drift emplacement mode and the thermal load of 83 metric tons uranium (MTU)/acre (Reference 5.10, Vol II, pg 4-5, 8-115 & 8-127). (This assumption is used in section 7.4.4)
- 4.3.2.6** Thirty-five channels from each borehole will be used to size the data acquisition system. This assumed value is used as a starting point pending additional concept development by affected organizations associated with the PC Program. Experience from ESF thermal testing indicates that over 5000 signals will be obtained from approximately 200 boreholes, which is approximately 25 signals per borehole (Reference 5.16, 3-9 through 3-16). It is assumed that the PC data collection densities will be greater than this value due to the increased length of the PC boreholes. This initial value will require further examination in later analyses, however, variations in this number can be readily accommodated without severely impacting the data acquisition network configuration. (This assumption is used in section 7.7.3)
- 4.3.2.7** There can be thirteen (13) boreholes per alcove arrangement off of the observation drifts. This value is based on providing the capability to obtain host rock data in multiple planes of the repository. This assumed value is used as a starting point pending additional concept development by affected organizations associated with the PC Program. This initial value will require further examination in later analyses, however, variations in this number can be readily accommodated without severely impacting the data acquisition network configuration. (This assumption is used in section 7.7.3)
- 4.3.2.8** There can be five observation drifts above the emplacement level to monitor repository performance. This value would provide coverage of approximately 20% of the number of emplacement drifts and can be used as a starting point for future analysis (Reference 5.6). (This assumption is use in section 7.7.3)

- 4.3.2.9** For work envelope and clearance considerations in Section 7.6.5, a waste package diameter of 2.0 meters was assumed. Rationale: the largest waste package diameter shown in the CDA is 1.97 meters (CDA DCWP 005). It was assumed that this value, rounded-off to 2.0 meters, would serve as the outer bound for the waste package diameter.

For the thermal analysis presented in Section 7.6.6, Attachment II and Attachment V, and also for the radiation shielding analysis presented in Section 7.6.7 and Attachment IV, a waste package diameter of 1.850 meters and a length of 5.850 meters was assumed. Rationale: These dimensions are based on the waste package identified in CDA EBD RD 3.7.1.J.1 which are more representative of the waste packages expected to emit the highest amounts of heat and radiation.

It is noted here that additional assumptions related to the waste package dimensions and the radiation shielding analysis are provided in Assumption 4.3.4.2.

- 4.3.2.10** The maximum speed of the inspection gantry vehicle, described in Section 7.6, is assumed to be 10 km/hr (2.78 m/s). It is further assumed that it will be accelerated from a standing stop to maximum speed in 20 seconds and decelerated from maximum speed to a standing stop in 4 seconds. Rationale: values are initial estimates only and are based on the overall design goal of developing equipment that is safe, reliable and power efficient. Slower speeds are conducive to these design goals and limit the possibility of accidents. The inspection gantry will not have exceptionally large loads to carry as the emplacement gantry does, and therefore should be permitted to operate at nominally higher speeds. Speeds of 8 km/hr have been suggested in relation to the emplacement gantry (Reference 5.10, Vol II, pg 8-218), therefore 10 km/hr does not seem an unreasonable assumption for the inspection gantry. Values are used in initial rough order-of-magnitude (ROM) estimates of in-drift resident times and power needs located in Attachment I.

- 4.3.2.11** The actual materials and components to be used in the Remote Inspection Gantry, as described in Section 7.6.5, have not yet been selected. For the purposes of this analysis, the structural frame and some instrument enclosures are assumed to be constructed from a generic unspecified steel whose density is assumed to be approximately 7800 kg/m³. Rationale: densities for carbon or chrome based steels listed in Reference 5.15, Table A-2, range from approximately 7,689 to 7,897 kg/m³, therefore 7800 kg/m³ is a reasonable approximation within this range. The density value is used in initial rough order-of-magnitude mass estimate in Attachment I, and initial thermal analysis in Section 7.6.6.

- 4.3.2.12** The actual instruments and electrical components to be used in the design of the Remote Inspection Gantry, as described in Section 7.6.5, have not yet been selected. As a starting point for initial estimates of the power needed to operate the Remote Inspection Gantry,

rough order-of-magnitude estimates were made of power required by various electrical components and subsystems (see Table I-2, Attachment I). The basis for these rough estimates is from a review of commercially available components with approximately similar technological sophistication as anticipated for use on the remote inspection gantry (see Attachment III and the technology surveys associated with References 5.7 and 5.8).

4.3.3 Specific Thermal Analysis Assumptions

The following assumed parameters were used in the thermal modeling and numerical analysis presented in Section 7.6.6, Attachment II, and Attachment V. These assumptions are being made early in the design process, even before selection of specific materials and components have been determined. These assumptions are intended solely to provide an initial starting point in rough order of magnitude estimates related to the viability of using remote systems in the anticipated elevated thermal environment within the emplacement drifts.

- 4.3.3.1** A constant waste package surface temperature of 200°C was assumed in numerical thermal modeling. Rationale: based on the information provided in the ACD report (Reference 5.10, Vol III, pg 6.2-32 to 6.2-33), the curves show WP surface temperatures approaching, but not reaching, 200°C, therefore 200°C was used as a conservative value.
- 4.3.3.2** A constant drift wall temperature of 200°C was assumed in numerical thermal modeling to represent the potential maximum temperature which could be experienced during the preclosure period. (Reference DCSS 023 of the CDA)
- 4.3.3.3** Internal heat sources of 100 and 400 watts were assumed to approximate the heat generated by various electronic devices used to operate the remote inspection gantry described in Section 7.6.5. The 400 watt value was assumed to provide an approximation of the upper limit of heat generation for any single electronic subassembly or component. Rationale: a) rough order-of-magnitude estimates of nominal power consumption discussed in Attachment I, and b) review of commercially available components with similar technological sophistication as anticipated for use on the remote inspection gantry (see Attachment III and the technology surveys associated with References 5.7 and 5.8).
- 4.3.3.4** The actual materials to be used in the Remote Inspection Gantry, as described in Section 7.6.5, have not yet been selected. In order to facilitate the initial thermal analysis contained in Section 7.6.6, the thermal properties identified in Table 4-1 were based on generic materials that provide an initial approximation of what eventually may be used. For example, it is assumed that the electronics box (also called the "device box") would be constructed of a type of stainless steel with thermal properties approximated by those

shown in Table 4-1 (see Reference 5.15, Table A-2, pg 636). For the insulation box, a generic, readily available fiber insulation board was selected for the initial thermal evaluation (see Reference 5.15, Table A-3, pg 639). This selection is conservative for two reasons: a) for all but one case the insulation material was assumed to be only 10 mm thick, and b) because there are other insulation materials available with much lower thermal conductivity if additional insulative capability were to be needed. In order to investigate the influence that the thickness of insulation material has on the internal temperature rise time, one of the cases (Case 3) was analyzed with a 50 mm insulation box wall thickness.

For the purpose of the initial rough order-of-magnitude thermal analysis presented in Section 7.6.6, Attachment II, and Attachment V, the thermal properties of the assumed materials can be approximated by the values listed in Table 4-1 (Reference 5.15, Tables A-2 and A-3).

**Table 4-1
Assumed Thermal Properties of the Electronics and Insulating Boxes**

Item	Electronics Box (i.e. "Device Box")	Insulating Box
Density (kg/m³)	7817	240
Thermal Conductivity (W/m-K)	16.3	0.048
Specific Heat (J/kg-K)	460	700

By inspection of Table A-10 in Reference 5.15 the emissivity for the electronics box and the insulating box modeled in the thermal analysis can be roughly estimated to be approximately 0.8 and 0.02 respectively. The exact value of the emissivity does not influence the results of this thermal analysis in a significant way.

In the cases that investigate the affect of active cooling (Case 6 and 7) a specific cooling fluid and method of application has not yet been conceptually designed or selected. However, for numerical modeling purposes, conservative values for both the fluid temperature and convective heat transfer coefficient were assumed. The cooling fluid was assumed to be a gas applied at a temperature of 0°C. In complex situations the value for the convective heat transfer coefficient is typically determined experimentally. However, preliminary estimates for this value can be obtained by examining Reference 5.15, Table

1-2, page 13. From this table two separate values for the convective heat transfer coefficient were chosen in order to provide insight into the sensitivity of the thermal analysis to these particular values. The values for the convective heat transfer coefficient selected for use in this analysis are $4.5 \text{ W/m}^2\cdot\text{K}$ and $12 \text{ W/m}^2\cdot\text{K}$. The former is based on free air convection over a vertical plate and the later is based on forced air convection with airflow at 2 m/s. Depending on factors such as the cooling fluid density and flow velocity, the convective heat transfer coefficient could be significantly higher (i.e. better at moving heat away) than the values assumed.

- 4.3.3.5 Components for the Remote Inspection Gantry, described in Section 7.6.5, have not yet been identified. The assumed dimensions of the electronics and insulating boxes, modeled in numerical thermal analysis are shown in Table 4-2 below.

Table 4-2
Assumed Dimensions for the Electronic and Insulating Boxes

Item	Electronics Box (or "Device Box")	Insulating Box (All Cases, Except 3)	Insulating Box (Case 3)
Width (m)	0.4	0.44	0.52
Height (m)	0.6	1.0	1.0
Length (m)	1.0	2.0	2.0
Thickness (m)	0.05	0.01	0.05

The dimensions identified in Table 4-2 and the spatial relationships between the computer models of the electronics box, insulation box, waste package and drift wall, are based on the general layout of the Remote Inspection Gantry described in Section 7.6.5. The dimensions selected are intended only to provide an initial approximation of distances and spatial relationships between the various components. As the Remote Inspection Gantry design continues to develop and mature, improved values can be substituted for those provided in this preliminary analysis.

4.3.4 Specific Assumptions for Radiation Shielding Analysis

The following assumptions are used in the preliminary shielding analysis presented in Section 7.6.7 and Attachment IV.

- 4.3.4.1** The assumed waste package content and fuel characteristics for radiation shielding analysis discussed in Section 7.6.7 and Attachment IV is consistent with Reference 5.10 and the following assumptions are made:

Content: 21 Pressurized-Water Reactor (PWR) spent fuel assemblies. Rationale: this is consistent with the design basis recommendations presented in the ACD report (Reference 5.10, Vol III, pg 5-7).

Characteristics: 4.2% initial U-235 enrichment, 48,086 MWD/MTU burnup, and 10 years decay from reactor discharge, where MWD/MTU means Megawatt-days per Metric Tons of Uranium (Reference 5.10, Vol III, pg 5-7).

Heavy metal loadings: 0.464 MTU per fuel assembly (Reference 5.40, pg 7). Rationale: A review of the information in Reference 5.30 indicates that the Babcock and Wilcox (B&W) 15x15 Mark B assembly, at 0.464 MTU/assembly, contains one of the highest listed PWR uranium loadings. This value is used in Reference 5.40 for source terms for design basis event analyses.

- 4.3.4.2** The assumed waste package maximum external dimensions for radiation shielding analysis are assumed to be 1.85 meters in outer diameter and 5.85 meters in length (CDA EBD RD 3.7.1.J.1). For shielding analysis, the uncanistered commercial SNF waste package is assumed in order to obtain conservative results. This waste package has dimensions less than the maximum dimensions assumed for inspection gantry envelope and clearance considerations. Consistent with Reference 5.36, pg 20, the following dimensions for the uncanistered PWR fuel waste package are assumed and used in the shielding analysis:

Fuel region diameter = 1220 mm
Fuel basket liner thickness = 16.8 mm
Waste package inner barrier thickness = 20 mm
Waste package outer barrier thickness = 100 mm
Waste package outer diameter = 1629 mm

In addition, an infinite axial length of the waste package containing 21 PWR fuel assemblies is assumed for conservatism. Rationale: This assumption results in a slightly higher dose rate. (Used in Attachment IV)

- 4.3.4.3 The following material data were assumed for the radiation shielding analysis, based on the data used in Reference 5.36. Rationale: These data are derived from the materials contained in the respective region, and are representative for radiation shielding analysis.

PWR Spent Fuel Assembly Constituents

(Data used for conversion to weight %, Ref. 5.36, p 49)

<u>Element</u>	<u>atoms/b-cm</u>
O	1.4127E-2
Cr	7.1994E-6
Fe	1.3406E-5
Zr	4.0290E-3
Sn	4.4155E-5
U-235	4.7717E-5
U-236	3.8027E-5
U-238	6.3510E-3
Pu-239	3.2181E-5
Pu-240	1.1558E-5
Pu-241	7.2740E-6

- 4.3.4.4 The maximum expected radiation level is assumed to be 100 Rem/hr. Rationale: Review of the information in Reference 5.10, Vol III pg 6.4-57, 6.3-167, 6.3-171, indicate that the highest surface radiation levels are approximately 65 Rem/hr for DHLW, 28.9 Rem/hr for the 21 PWR package, and 26.7 Rem/hr for the 44 BWR package. For the purpose of initial equipment shielding estimates, a conservative value of 100 Rem/hr will be assumed as an upper limit for use in determination of maximum shielding requirements. (Used in Section 7.6.7.2).

4.4 CODES AND STANDARDS

4.4.1 University of California Research Laboratory

UCRL 15673 Human Factors Design Guidelines for Maintainability of DOE
Nuclear Facilities, University of California Research Laboratory,
June 18, 1985

4.4.2 United States Department of Energy

DOE Order 6430.1A General Design Criteria, U.S. Department of Energy, 4/6/89

4.4.3 American National Standards Institute

ANSI-N42.18-1980 *"Specification and Performance of On-Site Instrumentation for
Continuously Monitoring Radioactivity in Effluents"*, 1980

4.4.4 Code of Federal Regulations (CFR)

CFR, Title 10 Energy, Part 60, Disposal of High-Level Radioactive Wastes in
Geologic Repositories, January 1, 1996

5. REFERENCES

5.1 not used.

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Management (OCRWM), *"Quality Assurance Requirements and Description"* (QARD),
DOE/RW-0333P, Rev..6

5.3 US DOE, OCRWM, *Yucca Mountain Site Characterization Project, Repository Design
Requirements Document*, YMP/CM-0023, Revision 0, ICN-1, Las Vegas, NV (commonly
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5.4 CRWMS M&O, *Controlled Design Assumptions Document*, , DI# B00000000-01717-
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- 5.6 CRWMS M&O, "*Subsurface Repository Performance Confirmation Facilities*", DI# BCA000000-01717-0200-00011, Rev. 00
- 5.7 CRWMS M&O, "*Preliminary Analysis of Remote Monitoring & Robotic Concepts for Performance Confirmation*", BCAI00000-01717-0200-00001 Rev 00
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6. USE OF COMPUTER SOFTWARE

6.1 Thermal Modeling Analysis Code - ANSYS

6.1.1 Computer Hardware

The computer hardware used to perform the thermal modeling analysis was a Silicon Graphics Indigo² Power Extreme Workstation with 320 megabytes (MB) memory (CRWMS-M&O Tag #700715).

6.1.2 Computer Software

The thermal modeling analysis used Revision 5.2 of the ANSYS program (Reference 5.14). This revision has been validated and verified (CSCI: 30013 V5.2SGI) on the computer hardware listed in section 6.1.1 (Reference 5.34).

6.1.3 Software Application

The computer software (ANSYS) used for the thermal modeling analysis was appropriate per capabilities and applications of the code and was obtained from Software Configuration Management in accordance with appropriate procedures. The code was used within the range of validation in the software qualification report. ANSYS, introduced in 1970 by Dr. John Swanson and Swanson Analysis Systems, Incorporated (SASI), is a general-purpose program, meaning that the program can be used in many disciplines of engineering that deal with topics including structural, geotechnical, mechanical, thermal, and fluids. The ANSYS Revision 5.2 is a menu-driven computer program and uses the Graphical User Interface (GUI) of the Unix X Window System (ANSYS 1995).

6.2 Radiation Shielding Analysis Code - MCNP4A

6.2.1 Computer Hardware

The computer hardware used for shielding analysis was an IBM compatible P5-90 desktop personal computer (CRWMS-M&O Tag. #110519).

6.2.2 Computer Software

The shielding design analysis used the MCNP4A code. The MCNP4A code has been fully validated and verified (CSCI: 30006 V4A) on the computer hardware listed in section 6.2.1 (Reference 5.28).

6.2.3 Software Application

The computer software (MCNP4A) used for the shielding analysis was appropriate per capabilities and applications of the code and was obtained from Software Configuration Management in accordance with appropriate procedures. The code was used within the range of validation in the software qualification report.

6.3 Use of Spreadsheet Software

Lotus 1-2-3, Release 5 spreadsheet software was used to produce graphs in this analysis. User defined formulas and/or algorithms are defined where used.

7. DESIGN ANALYSIS

7.1 Introduction

This analysis begins to develop and evaluate preliminary designs for acquiring repository performance information. It focuses on performance confirmation related activities during the period after the start of waste package emplacement and before permanent closure of the repository. This will be a period of time lasting up to 125 years.

7.2 Performance Confirmation Program Overview

Performance confirmation (PC) is defined in 10 CFR Part 60.2 as "the program of tests, experiments, and analysis which is conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure will be met." Subpart F of 10 CFR Part 60 provides general requirements for a performance confirmation program, as well as more specific requirements related to confirmation of geotechnical and design parameters, design testing, and monitoring and testing of waste packages.

The PC Program objectives are:

- ◆ Confirmation that subsurface conditions encountered and changes in those conditions during construction and waste emplacement operations are within the limits assumed in the licensing process.
- ◆ Confirmation that natural and engineered systems and components that are required for repository operations, or that are assumed to operate as barriers after permanent closure, are functioning as intended and anticipated (10 CFR 60.140). These components specifically include the waste package, drift backfill (if used) and borehole seals.
- ◆ Evaluation of compliance with regulatory and licensing requirements related to post closure performance.
- ◆ Evaluation of the repository readiness for permanent closure.

The MGDS PC program tests and evaluates the natural and engineered barrier systems of the repository to predict post closure waste confinement and isolation performance. It will rely on in-situ monitoring, field and laboratory tests, and experiments to collect data during repository construction and operation, which will be used to confirm predictions, evaluate pre-closure performance, and recommend corrective actions or repository closure.

7.3 Development of Performance Confirmation Data Acquisition Strategy

The Performance Confirmation Concepts Study Report (PCCSR) (Reference 5.5) was used as a starting point by the team members associated with the development of this analysis. The PCCSR provides a complete listing of "Key Performance Confirmation Parameters For Design", and makes recommendations on how, and with what frequency, these parameters might be acquired (see Section 5 and Appendix D of the PCCSR). In areas where additional clarification was needed, the design team met with the original authors of the PCCSR. Based on review of the PCCSR, discussions held in subsequent design meetings, and evaluation of the various design options, the following eight data collection strategies have been identified:

1. Sampling program
2. Geologic mapping program
3. Alcove-based testing in non-emplacement areas
4. Borehole instruments in the altered zone
5. Monitoring the ventilation system
6. Remote systems in the emplacement drifts
7. Contingency plans for additional alcoves, drifts or testing
8. Recovery of waste packages or testing dummy waste packages

The scope of this analysis focuses on developing design concepts for data acquisition in the following areas:

- Monitoring Ventilation System
- Monitoring Emplacement Drifts by In-situ Instrumentation
- Monitoring Emplacement Drifts by Mobile Remote Systems
- Instrumentation Installed in Boreholes from Observation and Perimeter Drifts
- Developing initial concepts for a subsurface data acquisition network

7.4 Monitoring Ventilation System

This section describes the development of initial design concepts for acquiring repository performance confirmation data by monitoring the exhaust air ventilation system.

7.4.1 Parameters to be Monitored

As stated in Section 4.3.1, CDA Key 061.10.h: "The air temperature, relative humidity, and gaseous radioactive emissions of all emplacement drifts shall be monitored through the drift ventilation." This assumption can readily be met by installing a temperature sensor, a humidity sensor, and a radiation sensor in the emplacement ventilation exhaust shaft, downstream of all emplacement drifts.

The problem with this installation is that when an anomalous parameter reading is detected, it will take a considerable effort to determine which drift, and subsequent waste package, may be the cause.

CDA Key 061.10.I recognizes this and states "The ventilation monitoring system shall be capable of identifying the specific drifts that are the sources of gaseous radioactive emissions, if any, within TBD hours of detection of such emission." This assumption can be met by installing a radiation sensor in the exhaust main, for example, for every ten emplacement drifts. When a gaseous radioactive emission is detected, the operators will be able to determine which block of ten emplacement drifts have a problem waste package. Further investigation would be necessary to determine exactly which drift requires attention. This concept, though better than the single point monitoring scheme, may not allow sufficient coverage. Additional options and alternatives are discussed below.

The same principles in the above paragraph for radiation can be applied to humidity and temperature. With only one point of measurement (exhaust shaft), it will take considerable effort to determine which drift and subsequent waste package is the cause of potential problems or out of range measurements. One of the purposes for measuring a parameter is to decrease the reaction time to abnormal conditions.

It is possible to monitor every emplacement drift exhaust raise. Radioactive emissions, if any, from the monitored drifts could be detected in a very timely manner. If high humidity or high temperatures are detected, a remote monitoring device could be sent into the drift to further investigate the anomaly. Appropriate off-normal operating procedures can then be executed.

An additional reason for monitoring each individual drift is that the emission of gas from a defective waste package may be a transient event that does not recur. Once any internal pressure is released, the package may not give further indication of leakage. Thus, if the gas is detected in the exhaust main only, finding the leaking waste package may not be possible unless all drifts are monitored.

The above discussion primarily addresses abnormal and upset conditions. However, by continuously monitoring each drift, a record of the exhaust conditions for that drift can be made. Air from each emplacement drift should therefore be monitored for temperature, humidity, and radiation. This information, when related to emplacement drift intake air conditions, may reveal the amount of moisture being removed from the drift, the approximate rock wall temperature in the drift, and would give notification of any gaseous radionuclide release due to a waste package breach.

7.4.2 Obtaining Drift Samples

The purpose of this section is to discuss the alternative methods for obtaining representative drift exhaust air samples for measurement. This section will discuss isolation door leakage, louvers in the isolation door, sample piping running from the drifts to the exhaust shaft area, and permanently monitoring the sample piping versus temporary monitoring.

7.4.2.1 Isolation Door Air Leakage

The drift isolation doors will be designed and installed to minimize air leakage. However, it is extremely difficult to prevent leakage entirely. The doors, though similarly constructed, will leak at different rates because of small variations in construction. Also, the location of the door within the subsurface ventilation network will cause leakage rates to vary. Doors closer to the north end of the block will experience a higher pressure drop across the door than those at the south end. Due to these conditions, sampling based solely on door leakage should not be attempted.

7.4.2.2 Controlled Flow Through the Isolation Door

An alternative to relying on leakage to achieve airflow is to incorporate a simple device into the door or door bulkhead which will allow a small, controllable quantity of air to pass. The device may be a set of louvers, a small sliding door, or simply a gate valve or butterfly valve. These devices can be set at various apertures to allow a consistent flow to pass regardless of the variations in pressure drop across the door. Design of the specific device is not within the scope of this analysis. Figure 7.4-1 shows an isolation door concept with louvers as an example. Figure 7.4-2 shows one arrangement of sensory equipment mounted in the exhaust raise.

7.4.2.3 Sample Piping

Another alternative for obtaining drift air samples would be to install two legs of piping from the top of the exhaust raise, down the raise and into the exhaust main as shown in Figure 7.4-3. The opening of the piping runs can be oriented so that air from each of the emplacement drifts (east and west) can be extracted. In the exhaust main, the piping can be connected to a discrete sealed exhaust duct which can contain any airborne contamination resulting from a leaking waste package (WP). Details regarding this type of sample extraction need to be addressed at a later time.

FIGURE 7.4-1
ISOLATION DOORS
W/ OPERABLE LOUVERS

FIGURE 7.4-2
EMPLACEMENT DRIFT AIR
MONITORING ARRANGEMENT 1

FIGURE 7.4-3
EMPLACEMENT DRIFT AIR
MONITORING ARRANGEMENT 2

A sample system that consists of a temperature sensor, humidity sensor, and radiation sensor can be installed in the piping before it enters the exhaust duct. Because the airflow for these alternatives will be relatively small, the air sample stream could be at elevated temperatures. Cooling of the air sample may be necessary to accommodate the operating temperature limits of the radiation and humidity sensors.

A combination of Arrangements 1 and 2 may be the best solution. A small controlled flow is allowed to pass each isolation door, and the exhaust duct arrangement in Figure 7.4-3 could be used to capture that flow, allowing discrete monitoring of each drift as well as containing the emplacement drift airflow in the duct work as opposed to releasing it to the general airflow in the main exhaust. Additional ventilation system design work is needed to fully validate this concept.

7.4.3 Sensors and Instrumentation

This section will discuss the various types of sensors which are capable of measuring the variables stated in section 7.4.1.

7.4.3.1 Radiation

There are instruments, such as the Geiger counter, that measure radioactive particles, film badges and pocket dosimeters that measure radiation doses, and ionization chamber type instruments that measure dose rate (Reference 5.32). Although there are many different instrument types, the operating principles for most radiation measuring instruments are relatively standard. The basic requirement of any radiation measuring instrument is that the instrument's detector interact with the radiation in such a manner that the magnitude of the instrument's response is proportional to the radiation effect or radiation property under measurement. It is important to also consider the robustness of the radiation sensors if they are to be deployed in elevated thermal environments for extended periods of time. However, as discussed in Section 7.4.2.3, it may be possible to mount sensors within the exhaust drift, where air temperatures will remain much cooler than in the emplacement drifts, and it may also be possible to cool the air sample prior to radiation detection measurements.

Particle counting instruments are frequently used by health physicists to determine the radioactivity of a sample taken from the environment, such as an air sample (Reference 5.32). The detector in particle-counting instruments may be either a gas or a solid type. In either case, passage of an ionizing particle through the detector results in energy dissipation through a burst of ionization. The burst of ionization is converted into an electrical pulse that actuates a readout device, or transmitter, where the count is registered.

Numerous vendors manufacture radiation transmitters. The transmitter outputs can be made in DC Volts or DC current, but must be determined at time of procurement. Voltage transmission signals are subject to electromagnetic interference and drops due to the resistance of the signal wiring (Reference 5.33).

7.4.3.2 Temperature

Resistance temperature detectors (RTDs), high temperature thermistors, and thermocouples (TCs) can be used for measuring and transmitting signals for the exhaust air temperature (Reference 5.22). These types of sensors are commercially available, can operate within the anticipated temperature ranges, are relatively inexpensive, and are reliable for long term monitoring.

A thermocouple is composed of two dissimilar metals which are joined at one end (Reference 5.22). When this joined end is heated, a continuous current flows in the circuit. The amount of this current flow and associated circuit voltage is a function of the junction temperature and the composition of the two metals. Thermocouple transmission signals are in millivolts DC and can be subject to electromagnetic interference, although advances in extension wire shielding have minimized these effects.

An RTD's electrical resistance changes in direct proportion to the surrounding temperature changes (Reference 5.22). Most RTDs are made out of platinum because platinum can withstand high temperatures while maintaining excellent stability and showing limited susceptibility to contamination. RTD transmission signals are in DC Ohms and the installed resistance of the "loop" must be taken into account at the time of installation. The four-wire configuration offers higher accuracy and resolution than a three-wire RTD.

Like the RTD, the thermistor is a temperature sensitive resistor (Reference 5.22). Of the three major categories of temperature measurement sensors, the thermistor exhibits by far the largest parameter change with temperature. Thermistors are generally composed of semiconductor materials which exhibit a negative temperature coefficient; that is, their DC resistance decreases with increasing temperature. Thermistors are generally limited to 100 °C, but high temperature versions are available. The four-wire configuration offers higher accuracy and resolution than three-wire thermistors.

The following depiction of the difference in the transmitted signal for a temperature change from 125 °C to 150 °C for a type J TC, a type E TC, a platinum RTD, and a thermistor is made (Reference 5.22):

Type J Thermocouple

Reading at 125 °C - 6.633 mV
Reading at 150 °C - 8.008 mV
Delta = 1.375 mV or 0.055 mV/°C

Type E Thermocouple

Reading at 125 °C - 8.029 mV
Reading at 150 °C - 9.787 mV
Delta = 1.758 mV or .07032 mV/°C

Platinum RTD (Alpha = .00385)

Reading at 125 °C - 147.94 Ohm
Reading at 150 °C - 157.31 Ohm
Delta = 9.37 Ohm or .3748 Ohm/°C

Thermistor (10,000 Ohm @ 25 °C)

Reading at 125 °C - 425.3 Ohm
Reading at 150 °C - 237.0 Ohm
Delta = 188.3 Ohm or 7.532 Ohm/°C

From the above information it can be seen that the thermistor exhibits the greatest sensitivity for a 1 °C temperature change. A problem with the thermistor is that it is a relatively fragile device that is not as rugged as a TC or RTD (Reference 5.22). The thermistor is also an extremely nonlinear device that is highly dependent upon process parameters. Consequently, manufacturers of temperature transmission and input devices have not standardized thermistor curves to the extent that TC and RTD curves have been standardized.

7.4.3.3 Humidity

Humidity is an expression of the amount of water vapor in air (Reference 5.21). There are two basic quantitative measures of humidity, absolute and relative. Absolute humidity is the amount of water vapor present in each unit quantity of air. It is often expressed as pounds of water/pound of dry air or grains of water/pound of dry air. Relative humidity compares the actual amount of water vapor present with the maximum amount of water vapor the air could hold at the given temperature.

Numerous vendors manufacture relative humidity transmitters such as Rosemount Analytical Inc., Vaisala Inc., General Eastern Instruments, and Endress + Hauser Instruments. If relative humidity and temperature are known, a simple calculation can be made to determine the absolute humidity of a given sample. The transmitter outputs can be made in DC Volts or DC current. Voltage

transmission signals are subject to electromagnetic interference and drops due to the resistance of the signal wiring.

7.4.4 Data Transmission

This section of the analysis will discuss how the data measured by the sensors in section 7.4.3 can be recorded, where the instruments and/or transmitters may be located, how the wiring may be routed, and how the data will end up in the PC system. The data acquisition system describes the process used to collect information to document or analyze a particular phenomenon. One of the first activities to investigate when designing a data acquisition system is the number of inputs and outputs (I/O). For the exhaust air monitoring portion of the performance confirmation (PC) program, there will be no outputs as the main purpose is to collect and compare the measured data.

From the information stated in section 7.4.3, there may be up to six channels per emplacement drift exhaust raise to be input into the PC data acquisition system. This can be the worst case if it is decided to utilize the sample piping to extract air from the emplacement drifts. Two channels will be needed to measure radiation, two channels will be needed to measure temperature, and two channels will be required to measure relative humidity resulting in six channels per exhaust raise. For example, a repository layout including 159 drifts (Section 4.3.1.1), including standby drifts, will need an exhaust air data acquisition network of 954 channels. It is common design practice to include 20 % spare input capacity when designing a system to account for anticipated as well as unanticipated changes. At this point in the design stage, it would be safe to use 1200 as the total required amount of I/O for the exhaust air monitoring acquisition system.

The transmitters for radiation, humidity and temperature will be located near the bottom of the exhaust raise as it enters the exhaust main. It is in the exhaust main that the acquisition hardware should also reside. This data acquisition hardware which will reside relatively close to the signal transmitters will consist of a controller board, I/O card racks, I/O cards, and cables which connect the I/O card racks to the controller board. The basic information flow will be that the transmitters are wired to the I/O card, the I/O card is connected to the backplane of the I/O rack, the I/O rack is cable connected to the controller board, the controller board then interfaces with higher level computer equipment which can display, trend, alarm, and store the data. Refer to Figure 7.4-4. Controller boards are usually limited in the number of I/O racks they can support. The cables that interconnect the I/O rack with the controller board also have distance limitations of usually several hundred meters. These limitations vary among manufacturers of data acquisition equipment.

FIGURE 7.4-4
SCHEMATIC BLOCK DIAGRAM
EXHAUST DRIFT MONITORING

NOTE:
THIS ARRANGEMENT IS FOR THE ILLUSTRATION OF
THE DRIFT TURNOVER SEQUENCE AND RESULTING
'DAS' HARDWARE LOCATIONS AND DOES NOT
SHOW ALL EMPLACEMENT DRIFTS.

LEGEND:

- CONTROLLER BOARD ENCLOSURE
- ▼ I/O RACK ENCLOSURE

FIGURE 7.4-5
EXHAUST DRIFT MONITORING
ARRANGEMENT

Data acquisition system equipment by its modular nature is extremely versatile and can be assembled to accommodate almost any possible measurement requirement in numerous ways. The following discussion will present one exhaust air data acquisition network to show the viability of such a system. Additional effort will be required to arrive at the most optimal installation from a cost, installation complexity, and maintainability standpoint.

During the course of repository operations, there will be a turnover sequence in which groups of drifts will be removed from the development side of the repository and placed on the emplacement side of the repository as the repository is constructed. This is significant as sufficient hardware should be installed to facilitate this turnover sequence. Sufficient I/O capability should be installed in each block of drifts which will be turned over. For example, this discussion will use thirteen as the number of drifts which will be turned over at a time (Section 4.3.2.4). For thirteen drifts, there will be 78 input channels required (6 per drift). These inputs can be accommodated by five, 16-channel input cards. Adding two cards for spares and design contingencies brings the total number of cards per turnover sequence to seven. This quantity of cards can be housed in one I/O card rack assembly which can typically house 4, 8, 12 or 16 cards (Reference 5.19).

The I/O rack cannot communicate with higher level process equipment and therefore requires connection to a controller board. Therefore in turnover block 1, there can be one controller board and one I/O card rack which contains seven input cards. Because controller boards can communicate with more than one I/O rack, all that is required in turnover block 2 is an I/O card rack which contains seven input cards. The I/O card racks can be mounted in the middle of the block of drifts to be turned over to minimize the amount of signal wiring from the transmitters. The controller board can be mounted at the end of turnover block 1 so the cabling to the I/O card racks is equidistant between the block 1 I/O rack and the block 2 I/O rack (roughly 150 meters each leg). Refer to Figure 7.4-5. This approach can be followed as the repository is constructed with odd numbered turnover blocks having an I/O card rack and a controller board mounted in them, and even numbered turnover blocks having only an I/O card rack mounted in them. With 159 emplacement drifts there will be a total of thirteen turnover blocks. If additional drifts are constructed, the additional I/O can be accommodated by installing another I/O rack, input cards and controller board as required.

In the above sequence, controller boards will be located at the southern ends of turnover blocks 1, 3, 5, 7, 9, 11, and 13. The distance between each controller board will be roughly 600 meters (26 drifts) (Section 4.3.2.5). To facilitate communication between each controller board and performance confirmation computer(s) on the surface, a fiber optic trunk line or backbone should be installed down the length of the exhaust main. Fiber optic cable is a transmission medium using light energy and as such provides an extremely high bandwidth, permitting data rates in excess of one billion bits per second. In addition to the very high bandwidth of fiber optic cables, they also have the advantage of being immune to electrical interference. Little or no signal attenuation occurs when a fiber optic cable is run in parallel with high voltage cables. (Reference 5.9)

The above discussion presents a viable alternative for the exhaust air monitoring data acquisition network for performance confirmation. A fiber optic trunk line can be run down the exhaust main and can be connected to controller boards which in turn can be connected to I/O racks which in turn can be connected to I/O cards which in turn can be wired to the radiation, humidity and temperature sensors. Sufficient spare input capability exists to accommodate the design as it progresses. If future boreholes and associated instrumentation for temperature, rock stress, rock strain, and deformation are constructed from the exhaust main, the I/O associated with these measurements can also be accommodated. More cards can be added, and if necessary more I/O racks. This concept has a very high degree of flexibility and adaptability and is well suited to the needs of the PC data collection portion of the program.

7.5 Monitoring Emplacement Drifts by In-situ Instrumentation

One potential data acquisition alternative not included in the PC strategy discussed in Section 7.3 is that of installing instrumentation *within* the emplacement drifts. One of the problems with this alternative is dealing with the harsh physical conditions inside the emplacement drifts. Sensors are routinely designed to detect process conditions at extremely high pressures, high temperatures and in very toxic gaseous environments for the refining, chemical and nuclear industries. These sensors monitor the process and transmit the control signals to control rooms via intricate electronics, power and signal wiring which are all installed external to the process. In the repository application, in-drift instrumentation would require that the sensor, transmitter, and associated wiring would need to be installed in the emplacement drift. In an approximately 100 year period, the sensors and/or transmitters will undoubtedly require calibration, maintenance and probable replacement. To perform these functions would require the development of intricate, expensive equipment such as robots, radiation shields, personnel protection, etc. How the harsh conditions and the inaccessibility for maintenance and calibration activities can be addressed requires additional design investigation and analysis.

Temperature sensing devices such as TCs and RTDs can sustain the ambient 200 °C temperature of the emplacement drift. High temperature wire is available for installations up to 400 °C, so the signals can be wired to external transmission or data acquisition equipment (Reference 5.22). The problem is that these devices, while extremely rugged, will not last forever. Maintenance and possible replacement of the TC or RTD assembly will eventually be required. A possible alternative would be to sacrifice the temperature sensors and take the data while they are still operable. This sacrificial approach then introduces other factors such as when the sensors eventually fail, how far back in time is the data still valid? Removal of the devices, associated wiring and any other installation hardware is another consideration. This alternative, while feasible, does introduce other concerns and design considerations that requires further investigation. Results of the current ESF thermal tests can be used to assess the viability of this alternative.

7.6 Monitoring Emplacement Drifts by Mobile Remote Systems

This section describes an initial design for a remotely operated inspection system that could be used to acquire repository performance information from inside emplacement drifts containing waste packages. The mobile remote inspection system is to be operated for limited intervals of time inside emplacement drifts containing radioactive waste packages where temperatures may reach 200 °C and radiation levels may be as high as 100 rem/hr. The system would allow repository personnel to obtain real-time visual, thermal, radiological and environmental feedback data in a surface-based control station facility.

This section discusses the in-drift parameters to be monitored (Section 7.6.1), design constraints (Section 7.6.2), concepts for equipment operation (Section 7.6.3), and the evaluation of design concepts (Section 7.6.4). Section 7.6.5 presents a single conceptual design, called the Remote Inspection Gantry, for consideration as the basis for viability assessment (VA) design.

Section 7.6.6 provides an important preliminary thermal analysis that examines the underlying feasibility and viability of exposing a device, such as the Remote Inspection Gantry, to the hostile thermal environment inside emplacement drifts. As discussed later in Section 7.6.6, initial results indicate a system like the Remote Inspection Gantry may be able to operate inside heated emplacement drifts for significant periods of time using only conventional thermal management design strategies.

Section 7.6.7 addresses radiation shielding issues and Section 7.6.8 discusses issues related to the costs associated with deploying an in-drift monitoring system such as the Remote Inspection Gantry.

7.6.1 Parameters to be Monitored

The parameters to be acquired by the mobile remote inspection system have been identified in the table entitled "Key Performance Confirmation Parameters For Design" (Reference 5.5, Appendix D). They include:

- Visual inspection of waste packages
- Visual inspection of emplacement drift facilities
- Monitoring waste package thermal characteristics
- Periodic emplacement and recovery of sample material test-coupons
- Monitoring possible ground water inflow

7.6.2 Requirements and Constraints

The Performance Confirmation Study Report (Reference 5.5) contains a list of "recommended design requirements" that have been incorporated in the CDA as Key Assumption 061 (Section 4.3.1). Several of these "assumed requirements" apply directly to the scope and functionality of a proposed mobile remote inspection system. Additional insight can also be obtained by examining the "Key Performance Confirmation Parameters" listed in Appendix D of the study referred to above.

A. Basic System Functionality: At a minimum, the proposed mobile-remote in-drift inspection system should be able to perform the tasks specifically identified in CDA 061 and the "Key Performance Confirmation Parameters For Design" table (Reference 5.5, Appendix D). This includes the following activities: inspect emplacement drifts at least once every ten years to monitor possible rockfalls, visually inspect waste packages, thermally image waste packages, provide seepage observations on emplacement drift perimeters and provide the capability to retrieve material coupons from emplacement drifts for offsite testing. Extended functionality beyond these basic, minimal, functions can be added as deemed necessary.

B. In-Drift Operating Environment: From a previous analysis (Reference 5.7) it is known that the operating environment inside the emplacement drift may reach temperatures of 200 °C and radiation levels approaching 100 Rem/Hr at the surface of some waste packages. The proposed mobile-remote in-drift inspection system will also need to operate within a confined work area. For equipment design purposes, the internal diameter of the emplacement drifts is approximately 5.1 meters and this diameter is partially occupied by cylindrical waste packages up to 2 meters in diameter (Sections 4.3.2.2 and 4.3.2.9).

C. Reasonably Available Technology: The scope-of-work for this analysis calls for the use of reasonably available technology. It is noted here that in the rapidly evolving and advancing world of remote systems design, technologies seen as available today may be obsolete within three to five

years. By the time a remote inspection system would be built for Performance Confirmation activities, the reasonably available component technologies of today might not exist in the future due to obsolescence. These technologies, however, will be replaced by others more advanced, and, therefore, the basic concepts should remain valid.

7.6.3 Method of Operation

To provide a high-level overview of how a remote inspection system could be implemented, a general concept-of-operations is presented.

The remote inspection system will be loaded, unloaded and transported from drift to drift by means of a specially equipped railcar. Due to the high temperature and radiation inside the emplacement drift, the drift isolation doors will be opened only long enough to deploy the remote inspection system and then the doors will be closed. The high temperatures will also limit the time that the proposed remote inspection system can be operated inside the emplacement drift. Real-time bi-directional communication will be established between the remote inspection vehicle and operating personnel seated at a control station. After the remote inspection system completes its assigned task, it will be removed from the emplacement drift, allowed to cool-off and prepared for its next assignment. All maintenance and servicing activities related to the remote inspection system will be performed either in human-rated areas in the subsurface or at a maintenance area on the surface. The two basic operating modes that can be used to control the remote inspection system are teleoperation and supervisory control. Under teleoperation control a human operator will be provided with manual controls that remotely command and control individual actions on the inspection vehicle. Every action will be under direct human command including vehicle motion, speed and acceleration, movement of camera systems and remote manipulators, etc. Under supervisory control the remote inspection system will be commanded to perform a set of pre-defined tasks semi-autonomously, but under the constant monitoring and supervision of a human operator. For example, the remote system may be commanded to travel a set distance inside the drift and then stop and begin a visual scan of the area.

Operators will be able to control the remote inspection system from a control console located in a facility on the surface. The operators seated at the control console will be provided with multiple live high-resolution video images of the remote system performing its inspection task inside the emplacement drift. A graphical user interface on the computer consoles will provide real-time performance information on the status of all remote vehicle subsystems, including such parameters as status of the primary and backup power supplies, internal temperatures, motor torque loads, etc.. The control computers will continuously monitor every aspect of equipment operation and performance and provide early warning signals and/or alarms to alert the operators should any parameter approach predefined operational limits.

7.6.4 Evaluation of Design Concepts

This section evaluates three conceptual designs proposed in an analysis entitled: "Preliminary Analysis of Remote Monitoring & Robotic Concepts for Performance Confirmation" (Reference 5.5). The three concepts presented within that reference were:

- Remote Inspection Gantry
- Overhead Monorail Inspection
- Mobile Rover Inspection System

The proposed Remote Inspection Gantry concept employs a mobile inspection vehicle that would ride on existing rail systems used during the waste package emplacement process. The inspection gantry would be designed to arch over the emplaced waste packages and provide an observation base for remote inspection and viewing. This concept underwent two design iterations (See Figures 7.6-1 and 7.6-2). The initial design iteration (Figure 7.6-1) did not appear to provide reasonable space for the multiple control and instrumentation packages that it would need to carry. It also would be more challenging to shield components from the elevated temperatures and radiation. As will be shown hereafter, the later design concept (Figure 7.6-2) was selected for further evaluation.

The Overhead Monorail Inspection System concept would utilize a multi-purpose inspection platform that could carry an array of instruments and provide basic visual, radiological and thermal inspection capabilities. The inspection system would ride a rail system mounted to the crown of the drift. In the course of the evaluation within this analysis, this concept was altered to utilize a dual rail crown-mounted "Overhead Inspection Cart" design rather than a mono-rail design in order to provide a more stable base from which to make observations and manipulate or retrieve sample test-coupons (see Figure 7.6-3).

The Mobile Rover Inspection System concept was briefly evaluated. It consisted of developing a small wheeled vehicle that would carry a small payload of miniaturized instruments for remote in-drift inspection. Due to the inherent and obvious limitations of the design concept, which include: having a small payload for add-on instruments, having a small mass which increases difficulties in regulating internal temperatures, difficulties in supplying power, difficulties in traversing the drift invert design, significantly higher development costs, etc., this concept was not considered further within this analysis.

Table 7.6-1 shows the evaluation of several design considerations and issues as they relate to the Remote Inspection Gantry and the Overhead Inspection Cart. Both of these concepts appear technically achievable, however, the intent of this evaluation is to pick the better of the two concepts presented and use it as the basis for further concept development.

FIGURE 7.6-1
REMOTE INSPECTION GANTRY
DESIGN CONCEPT 1

FIGURE 7.6-2
REMOTE INSPECTION GANTRY
DESIGN CONCEPT

FIGURE 7.6-3
OVERHEAD INSPECTION CART
DESIGN CONCEPT

Table 7.6-1

Concept Design Comparison and Evaluation

Design Issues	Remote Inspection Gantry Concept	Overhead Inspection Cart Concept
Functionality (identified in Section 7.6.2)	Can accomplish the minimal functions listed in Section 7.6.2. This concept has a larger and more versatile mounting platform for instrumentation and accommodates multiple camera views.	Can accomplish the minimal functions listed in Section 7.6.2. However, this concept provides only overhead view angles. The mounting space for instruments is more restricted. More difficult system installation and recovery within the emplacement drifts.
Reliability	Due to the significantly larger payload, this design can accommodate parallel redundant systems more easily. Easier to protect components from heat.	Will require more design effort and development work to ensure system reliability.
Maintainability	This design concept could be designed for easy maintenance outside the emplacement drifts.	This design concept could be designed for easy maintenance outside the emplacement drifts.
Customization Required, Utilization of Existing Infrastructure	This design concept utilizes the rail and power systems that could be installed in the drifts for emplacement activities.	This concept will require additional rail and power systems to be installed to support its operation.
Thermal Management Issues	This concept has a much larger thermal mass which extends the time before internal temperatures rise.	Lesser mass, quicker heat up. Less room to accommodate reservoirs for active cooling.

Based on the foregoing brief evaluation, the Remote Inspection Gantry was selected as the better of the two concepts considered and will be the focus of further development within this analysis.

7.6.5 Remote Inspection Gantry: Design Concept

The general approach for developing the Remote Inspection Gantry design concept is to develop a simple, robust and very reliable base vehicle. The components comprising the base vehicle system, including locomotion, power and communication systems, will utilize well proven and reliable technologies. Beyond this, these components will each have physically separate and redundant backup systems that will further ensure the reliability of the base vehicle.

One of the most critical aspects of the design is ensuring that the vehicle transportation system, i.e. the locomotion drive system including the braking system, will operate reliability and enable the inspection gantry to be recovered from the emplacement drifts when commanded. The add-on instrumentation such as the vision, thermal, radiological and environmental sensor systems will be designed such that they will not adversely affect the underlying reliability of the vehicle transportation system. The vehicle locomotive system is discussed later in this section.

Another critical element of the design is the thermal control system. With the ambient operating environment inside the emplacement drifts approaching 200 °C, and with many commercially available electronic components limited to temperatures below 50 °C, it will be important to protect sensitive components from the elevated temperatures. The strategy for the thermal control system is discussed later within this section.

Since thermal design issues are such important factors in assessing the viability of this design concept, an initial thermal analysis has been performed to examine several fundamental thermodynamic considerations. This preliminary thermal analysis for the Remote Inspection Gantry is discussed below in Section 7.6.6.

Key Subsystems: The design of the Remote Inspection Gantry can be broken down into the design of several key subsystems which include: 1) the mechanical structure of the vehicle, 2) the method of locomotion, 3) on-board control and communication systems, 4) thermal control systems, 5) power systems, and 6) sensors and instrumentation systems. The following paragraphs briefly discuss design issues related to each of these subsystems. Figure 7.6-4 shows the conceptual design for the Remote Inspection Gantry, and Figure 7.6-5 provides a schematic block diagram of the internal electronic systems.

FRONT VIEW

SIDE VIEW

DETAIL A

ISO VIEW

FIGURE 7.6-4
REMOTE INSPECTION GANTRY

FIGURE 7.6-5
REMOTE INSPECTION GANTRY
SCHEMATIC BLOCK DIAGRAM

Mechanical Structure: Because of the high load carrying capacity of the rail system, the Remote Inspection Gantry can be designed with a heavy, rugged, mechanical structure. In fact the heavier the gantry is, the more thermal mass it has and the longer it will take to heat up internally. A heavier vehicle mass will also provide good stability for manipulation and other sample collection activities. The trade-off issue is that a heavier inspection gantry will require more energy to accelerate and decelerate. It is envisioned that the basic mechanical frame work of the Remote Inspection Gantry will be fabricated from tubular steel to which locomotion, controls and instrumentation systems can be mounted. The external surfaces of the gantry frame can be covered with a series of external thermal and radiation insulating panels that will block out the majority of the thermal energy radiated from the waste packages and the surrounding drift walls.

Inside these removable thermal insulation panels additional design measures can be taken to enhance heat rejection rates from the surrounding environment. In the concept that is presented in this analysis, the protected internal areas of the gantry will be occupied by several sizes and types of electronic boxes that provide not only protection from the harmful effects of nuclear radiation but also provide a substantial heat sink for internally generated heat from operating electronics. These "cool boxes" will be designed to maintain internal temperatures less than 50°C.

Initial rough order-of-magnitude estimates of the overall mass of the Remote Inspection Gantry are provided in Attachment I. These estimates indicate that the inspection gantry may have an overall mass of about 2900 to 4700 kg, depending on how much radiation shielding material is needed (See Section 7.6.7). The initial mass estimates are needed later in the analysis to help in the initial assessment of power and thermal control needs and to see if basic design parameters are consistent with a viable design.

Vehicle Locomotion: The Remote Inspection Gantry design concept can make full utilization of the infrastructure that can be installed for waste package emplacement activities. It can be designed to use the same rail system and the same third rail (conductor bar) power delivery system used during the waste package emplacement process.

A reliable vehicle locomotion system is critical to the overall success of the Remote Inspection Gantry. Therefore, the locomotion systems will be designed with a series of parallel redundancies to eliminate the possibility of single point failures. The Remote Inspection Gantry can be designed with four independent but electronically integrated drive motors and wheel assemblies, with one assembly located near each corner of the vehicle's base frame. Each of these motors individually would have the capability to move the inspection gantry to safety. This drive concept is successfully implemented by commercial crane companies in crane designs that have been approved by the NRC for handling nuclear materials (see Attachment III). There will also be redundancy built into the motor control electronics by housing identical controls on opposite sides of the vehicle.

The drive motors for vehicle locomotion will be a primary consumer of power on the Remote Inspection Gantry. A preliminary estimate of the power needs associated with the vehicle locomotion system are provided in Attachment I. In order to facilitate the estimating process, typical operating scenarios and duty cycles were identified and initial approximations were made for maximum vehicle operating speed (10 km/hr), acceleration (0.139 m/s^2) and deceleration (0.556 m/s^2). The evaluation in Attachment I indicates that, at a speed of 10 km/hr, the Remote Inspection Vehicle might be able to perform a round trip, nonstop, survey of the longer emplacement drifts in approximately 10 minutes.

The evaluation in Attachment I also indicates that accelerating the mass of the inspection gantry vehicle consumes considerable power, while, because of the low rolling resistance inherent in the steel rail design, maintaining the vehicle at a constant speed requires very little power (less than 20 watts). Typically, drive motors become less efficient as ambient temperatures rise although special high-temperature radiation hardened motors are available. A means will be needed to provide for dissipating heat generated by the motors.

There will be several safety factors and design approaches that can dramatically reduce the possibility of derailment. These include: heavy-duty high-quality rails, high quality rail mounts to concrete inverts, slow speeds, straight line motion with no curves to negotiate, no rail switches inside emplacement drifts, double flanged wheels, fore and aft looking camera systems, and rail continuity sensing (note: excessive speed, loss of braking or control on hills, rounding curves too fast and malfunctioning rail switches are typically the primary causes of derailment for rail-based vehicles. It is noted here that this design will not have to contend with these factors).

On-Board Control System: There are controls critical to operation of the gantry vehicle transportation system and there are controls that support operation of add-on instrumentation which are not critical to reliable vehicle operation. The control system, therefore, can be logically divided into two categories based on function: 1) the vehicle control system, and 2) the instrumentation control system, which includes control of equipment such as camera systems and the remote manipulator arms.

From a controls standpoint, the base inspection gantry vehicle will be relatively simple to control. The vehicle will only travel forward and backward on a relatively flat rail lined surface. It is a one-degree-of-freedom system. There is no need for steering, rapid accelerations, high speeds, sudden stops, path planning, advanced navigation, and so on. The vehicle control system will need to control and monitor the drive motors; the braking system; and the position, velocity and acceleration sensors. Reliable drive and braking systems are readily available and well proven. Thermal control measures will be taken to ensure that the motors and control electronics do not over heat. Vehicle performance sensors, such as motor torque (i.e. current) sensors, temperature sensors, etc., will also provide additional system performance monitoring capabilities. The vehicle control system can be

simple and reliable with no more sophistication than the control systems now used to operate NRC approved gantry cranes (Attachment III, see Ederer Cranes). As with these cranes, the vehicle control system can be based on reliable and well proven PLC technology (Programmable Logic Controllers, which are used extensively in industrial control applications). See the schematic block diagram of the internal electronic systems shown previously in Figure 7.6-5.

The instrumentation control system will also be designed and built for robust and reliable service. However, there may not be a need for the same level of component redundancy as is needed for the vehicle control system. Should an instrument not function correctly, the Remote Inspection Gantry can be recovered from the emplacement drift and the instrument can then be repaired or replaced.

The instrumentation control system should be equipped with more asynchronous computational power than is typical of current PLC technology. The hardware architecture for the instrumentation control system can be based on industrial computer technologies (See Figure 7.6-5). It will provide extensive on-board system memory and data processing and storage capabilities. The instrumentation control computer would support parameter measurement and processing, control of the vision and lighting systems, control of the thermal and radiation monitoring systems, and control of the remote manipulator arms. It can also monitor higher level vehicle performance parameters such as overall power usage, heat build-up and distribution.

As indicated in Figure 7.6-5, the command, control and telemetry functions of the Remote Inspection Gantry will be provided by dual redundant PLCs and instrumentation computers, with matched components housed on opposite sides of the gantry vehicle.

Other contingency measures can include the implementation of "fail-safe modes". On loss of power or communication, the vehicle can be set to automatically switch over to auxiliary backup power and then follow a predetermined routine which may involve switching off all non-essential systems, retracting the manipulator arms to a safe configuration, and waiting a prescribed amount of time. If power or communication has not been restored within a reasonable amount of time, the vehicle will drive itself under reserve power back to the entrance of the emplacement drift.

Another key aspect of control system design is the development of reliable and robust control software. The hardware and software interfaces between gantry subsystems, and between the gantry and the surface facilities, and between the control consoles and the operators, will be extensive. The scope of the control software associated with the Remote Inspection Gantry, and its criticality to the overall reliability of the system, will warrant a significant development and testing effort.

It is noted here that the currently available control technologies are evolving and advancing at a rapid pace. Discussion of specific technologies may help to establish the viability of a concept, however, in all likelihood, specific technologies mentioned may be obsolete by the time this system would go into fabrication.

Vehicle Power System: A reliable uninterruptable source of power is essential to the operation of the Remote Inspection Gantry. The current design concept will utilize the same electrified third-rail (conductor bar) system used during the waste package emplacement process. This concept is reliable, thermally robust, and requires essentially no in-drift maintenance. As indicated previously in Figure 7.6-4, dual redundant power pickup mechanisms will be employed to ensure a reliable and continuous source of power. Power and vehicle electrification design concepts for mobile subsurface equipment are the focus of a separate analysis now in progress.

There will also be an auxiliary backup power system that will provide a limited amount of emergency power. It should be sized to provide enough energy to operate a minimal set of control electronics and also drive the vehicle back out to the emplacement drift entrance. A storage battery source that is operated only in an emergency may be sufficient.

There is a direct relationship between the amount of electrical power consumed by the inspection gantry and the amount of internal heat that will be generated. The internal heat will have to be dissipated within the system since the elevated temperatures outside the gantry provide little capacity to dump waste heat. The electronic components on-board the inspection gantry will be distributed in various electrical enclosures, or "cool boxes", mounted throughout the inspection gantry system. It is also pointed out that the electrical components and subsystems on the inspection gantry will not all need to operate simultaneously.

This analysis is early in the design process and specific electrical components have yet to be identified. Nevertheless, it is helpful to make an initial rough order-of-magnitude estimate of power levels that may be needed to operate a vehicle such as the Remote Inspection Gantry. Attachment I contains an initial estimate of power requirements needed for electrical systems on-board the inspection gantry. The estimate is based on conventional, commercially available, systems, and indicates that a vehicle such as the Remote Inspection Gantry might need approximately 1,500 watts of power nominally and perhaps up to 6,800 peak watts. However, at this point in the estimating process no attempt was made to evaluate the benefits of utilizing low-power technologies or energy conservation techniques such as those discussed in a prior analysis (Reference 5.7).

Thermal Control System: Thermal control will be of key importance to the overall survival of the Remote Inspection Gantry as it enters emplacement drifts where temperatures approach 200 °C. Strategies and design issues related to the thermal control of remotely operated vehicles were discussed in a prior analysis (Reference 5.7). They include: limiting time of exposure, thermal insulation (heat rejection) technologies and strategies, active and passive cooling systems for internally generated heat, use of thermally robust power and communication technologies, limiting (or alternating) duty cycle of power intensive components, use of low power electronics and

components, use of heat tolerant electronics and hardware, and prudent layout of thermal conduction paths for high heat components. Refer to the prior analysis for additional discussion of these design issues and strategies.

In order to begin to answer some basic questions related to the overall feasibility of deploying a remote inspection system for use inside 200 °C emplacement drifts, a series of finite element thermal analysis models are evaluated in Section 7.6.6.

Communication System: The communication systems for the Remote Inspection Gantry will utilize technologies and design concepts similar to those under consideration for the waste package Emplacement Gantry (Reference 5.9). Because of the critical need for reliable communication, redundant communication systems will be used. Three strategies will be used including: 1) using diverse technologies, e.g., leaky feeder, direct radio, or slotted microwave technologies, 2) using parallel systems, e.g., using two sets of independent radio components, and 3) physically separating the redundant communication systems, e.g., housing separate sets of components on opposite sides of the gantry. See Reference 5.9 for additional discussion of communication technologies that are being considered.

Sensing and Instrumentation Systems: The Remote Inspection Gantry will be a flexible and versatile mounting platform on which a variety of instruments can be mounted. Mechanical, electrical and computing interfaces will be provided for quick installation and removal of instrument packages and payloads. The Remote Inspection Gantry can be designed to be easily reconfigured with new suites of instrumentation to accomplish a particular task. The control system will be designed such that should one of these instruments fail it would not incur the otherwise normal and safe recovery of the vehicle from the emplacement drift. There are five basic instrument packages that are being considered, they include:

- The Vision System
- Thermal Sensing Instruments
- Radiation Sensing Instruments
- Air/Gas Sensing Instruments
- The Remote Manipulation System

Design issues related to these systems and the Remote Inspection Gantry are discussed below. Additional information can be found in the "Preliminary Analysis of Remote Monitoring & Robotic Concepts for Performance Confirmation" (Reference 5.7).

The Vision System: High-resolution CCD (Charged Coupled Device) cameras are fairly inexpensive components. Their low cost and ease of integration can justify the use of multiple cameras. On the Remote Inspection Gantry it is envisioned that several separate cameras can be used. There can be two high-resolution, high-zoom, forward-looking cameras and two facing aft, each mounted to a pan/tilt unit for positioning. There can also be 2 cameras mounted at the wheel level, called toe cameras, to provide imaging of the lower surfaces of the waste packages. Special high temperature, high-radiation, cameras are available and can be used (Reference 5.7 and 5.8). The camera systems can be mounted behind double pane insulating glass windows for increased thermal protection. A seventh camera could be configured into an end-effector, or gripper, on the remote manipulators. The end-effector mounted camera would be used for only intermittent observations and could be well insulated and stored in a cool area on-board the gantry when not in use.

In addition to CCD cameras, other types of vision-based systems could be integrated into the Remote Inspection Gantry and remote manipulator end-effectors. The vision system could include such technologies as laser cameras, boroscopes, fiberscopes, and optical periscopes, that will permit close-up, high-resolution visual inspection of key areas of interest like waste package welds.

Coupled to the operation of the camera system is a series of external high-intensity lights. These light systems will consume considerable amounts of power which in turn produces heat. Special lighting fixtures are available that can tolerate high heat levels above 400°C (Reference 5.11, pg 8-7). The lights will be mounted near external surfaces of the inspection gantry and will be insulated to prevent radiating heat toward internal components.

Thermal Sensing Instrumentation: There are two aspects to the thermal sensing instrumentation that will be used on the Remote Inspection Gantry. Some sensors will be used to monitor the performance of the gantry itself and the others will monitor the emplacement drift environment, specifically surface temperatures on the waste packages and surrounding structures. Thermocouples and thermistors will be mounted throughout the Remote Inspection Gantry and on-board instrumentation to continuously monitor system performance. Equipment operators will be alerted if any temperatures begin to approach predefined operational limits necessitating the gantry to be removed from the emplacement drift. Air temperature can be measured continuously along the emplacement drift during an inspection cycle. Drift wall and waste package surface temperatures can be obtained by pyrometer, infrared (IR) camera or thermal probe. These concepts are discussed further in Reference 5.7.

Radiation Sensors: Various types of radiation monitoring sensors can be used in conjunction with the Remote Inspection Gantry. The radiation sensor package may consist of air radiation sensors that will continuously monitor the air for minute traces of radionuclide gases, indicating that a waste package has developed a leak. Dosimeters will record cumulative dose radiation exposure to the Remote Inspection Gantry as a whole. Individual sensors may monitor dose exposures to sensitive electronics mounted internal to the inspection gantry. It may also be desirable to use gamma radiation cameras that will map radiation levels throughout the entire drift. These concepts are discussed in more detail in Reference 5.7.

Air/Gas Sensors: In addition to the thermal and radiological air measurement identified previously, it may be valuable to also monitor humidity levels across the drift. Air sampling systems could also support monitoring of other chemicals or gases of interest, such as carbon monoxide, or tracer gases if used in the waste package. This capability and related instrumentation are discussed further in a prior analysis (Reference 5.7).

Remote Manipulation System: There is a need to emplace and recover samples, or test-coupons, of various materials within the emplacement drift. According to the Performance Confirmation Concept Study (Reference 5.5), the sizes of the samples being considered range from small 50 mm square sample blocks to welded mockups of waste package end sections. Remote manipulators have been used in hot cells for decades. Thermally robust manipulators can be designed that are articulated by metal drive belts which allow the drive motors and control electronics to be housed within the protected and cool environment inside the inspection gantry housing. The basic end-effector, or gripper, can also be designed to be thermally robust and can be equipped with sensors and mini-cameras. The end-effector would be designed with a quick disconnect to allow end-effectors to be stored in a cool box until needed to perform a task.

The remote manipulator arms for the inspection gantry are envisioned to be of a fairly simple design. Many examples can be cited of robust and reliable manipulators operating in adverse conditions. (see Attachment 5 of Reference 5.7) As a fail-safe measure, the Remote Inspection Gantry's manipulator system can be designed such that under power-off conditions the manipulators automatically retract to a centered, arm-down configuration. This automatic retraction could be by means of spring loaded devices or simply due to the way the arm mass is balanced. If needed, additional safety precautions could be implemented in the arm design such as breakaway joints that give way if prescribed design loads are exceeded.

Additional Types of Instrumentation: The Remote Inspection Gantry design will be flexible enough to accommodate a wide variety of monitoring and inspection instruments. As technology advances, new instruments can be incorporated and upgrades to existing instruments can be made.

7.6.6 Remote Inspection Gantry: Thermal Analysis

In assessing the feasibility and viability of the Remote Inspection Gantry concept, one of the fundamental questions that needs to be addressed is, how long could the system be exposed to a 200°C emplacement drift environment before temperatures internal to the gantry rise above acceptable levels? The answer to this question will indicate how long the system can perform inspection activities before being removed from the drift. The objective of the thermal analysis within this section is to begin to explore the answer to this question.

In order to facilitate an initial understanding of the underlying thermal characteristics and interactions of the drift, waste package, and key components of inspection gantry, the thermal analysis problem was broken down into simplified models and representations of these systems. For example, in this initial analysis a small metal box, representing an electronic enclosure, was placed in a computer model of the emplacement drift and waste package. The "electronics box" (also referred to as the "device box") in the model is located in a position approximating where it might reside if it were inside one of the legs of the Remote Inspection Gantry. The electronics box wall thickness represents the steel that might serve as radiation shielding for the electronics. The wall thickness of the box is an assumed value as indicated in Section 4.3.3.5, Table 4-2. This simplified model was then evaluated under several different conditions. Each case provides insight into the thermal effects of altering basic design parameters, such as adding insulation, adding the factor of internally generated heat, or adding a simplified representation of active cooling to the model. For the case of examining the effect of adding insulation, a larger box, i.e. an "insulating box", representing the insulative exterior panels on the Remote Inspection Gantry, is added to the model (See Figures 7.6-6 through 7.6-9).

The goal of the numerical analysis is to provide a rough estimate of how long it would take before temperatures inside the electronics (or device) box would exceed 50°C which represents the upper operating temperature limit for many commercially available electronic devices.

The generic electronics box described above was selected for evaluation because it is probable that some of the electronic components will be the most thermally sensitive and vulnerable items on the Remote Inspection Gantry. By focusing the analysis on the electronics box it is assumed that the thermal requirements of other less sensitive components can also be accommodated. For example, it is well known that the drive motors will: a) be a primary source of internal heat generation which will need to be dissipated (see Attachment I), and b) the efficiency of motors decrease with increases in temperature. However, motors can operate in ambient temperatures well above the 50°C that is a limiting factor for the electronics. As the design progresses it will be important to thermally analyze the drive motors on the Remote Inspection Gantry, however, for this initial analysis it was assumed that the thermal performance of the drive motors would not be the limiting feature of the design.

Figure 7.6-6

Thermal Model, Isometric View

Model configuration depicts general arrangement of an emplacement drift, waste package, and electronic and insulating boxes representative of devices used on the proposed Remote Inspection Gantry (Case 2 shown, configuration is similar for Cases 3 through 7). Models are shown with finite element meshes.

Figure 7.6-7

Thermal Model, Section View

Model configuration depicts general arrangement of an emplacement drift, waste package, and electronic and insulating boxes representative of devices used on the proposed Remote Inspection Gantry (Case 2 shown, configuration also similar for Cases 3 through 7). Models are shown with finite element meshes.

Figure 7.6.8 **Electronics Box, Isometric View**
Finite element model of the "electronics box" (also referred to as the "device box") used in this analysis to represent a possible enclosure for electronic devices used on the Remote Inspection Gantry.

Figure 7.6-9

Insulation Box, Isometric View

Finite element model of the "insulation box" used in this analysis to represent the exterior insulation panels on the Remote Inspection Gantry.

7.6.6.1 Heat Transfer Mechanisms

The heat transfer mechanisms associated with the Remote Inspection Gantry operating inside a pre-heated emplacement drift, with high temperatures on both waste package and drift surfaces, involve mainly conduction and radiation. Convective heat transfer will occur if an active or passive cooling device is built into the inspection gantry.

When a room-temperature electronics box enclosure is moved into a hot emplacement drift, heat transfer will occur from the waste packages and heated drift wall to the electronics box through electromagnetic radiation as a result of temperature differences between the waste package and drift surfaces and the electronics box enclosure. The heat will gradually penetrate through the insulating medium by conduction due to the thermal gradient between the inside and outside of the box. Similar heat transfer mechanisms will occur between an outer insulating box and the inner electronics box. In addition, operating electronic devices inside the electronics box will also generate a certain amount of heat, and this heat will then be transferred to the air and on to the metal electronics enclosure box by a combination of free convection and conduction.

According to the first law of conservation of energy, thermal energy is conserved. So the general three-dimensional heat-conduction equation (Fourier's law of heat conduction) for the insulating and shielding boxes can be expressed in Cartesian coordinates as (Reference 5.15, Holman, 1986):

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) + q''' = \rho c_p \frac{\partial T}{\partial t} \quad (7-1)$$

Where

T	=	temperature, K
t	=	time, s
k	=	thermal conductivity, $W/m \cdot K$
ρ	=	density, kg/m^3
q'''	=	heat generation rate per unit volume, W/m^3
c_p	=	specific heat, $J/kg \cdot K$

For a Remote Inspection Gantry with an active or passive cooling device, the overall effect of convection can be evaluated using Newton's law of cooling:

$$q = hA(T_w - T_p) \quad (7-2)$$

where

- q = heat flow rate, W
- h = convection heat transfer coefficient, $W/m^2 \cdot K$
- A = convection surface area, m^2
- T_w = box surface temperature, K
- T_f = cooling fluid temperature, K

The heat from the waste packages and drift wall to the system of boxes is transferred mainly through thermal radiation. In this analysis, it is assumed that the waste packages are maintained at a constant temperature of $200^\circ C$ (Section 4.3.3.1) and the metal electronics box is housed inside the larger insulating box and that both boxes are completely encircled by the surrounding drift wall, which is also kept at a constant of $200^\circ C$ (Section 4.3.3.2) in this model (see Figures 7.6-6 and 7.6-7). The total radiant exchange can be calculated with the Stefan-Boltzmann law (Reference 5.14, Vol IV, page 6-3, equation 6.1-11):

$$q = \sigma \epsilon F_{pw} A (T_p^4 - T_w^4) \quad (7-3)$$

where

- σ = Stefan-Boltzmann constant with a value of $5.669 \times 10^{-8} W/m^2 \cdot K^4$
- ϵ = effective emissivity, dimensionless
- F_{pw} = view factor from the waste package or drift surface to the box surface, dimensionless
- A = surface area, m^2
- T_p = absolute temperature of the waste package or drift surface, K
- T_w = absolute temperature of the box surface, K

It is noted that the thermal response within the electronics enclosure box with the addition of an active cooling device is temporal and spatial, and the modeling inputs such as the cooling fluid temperature and convection heat transfer coefficient vary with time and location. More accurate modeling may require more complex computations involving time-dependent and three-dimensional fluid dynamics models, combined with a numerical trial-and-error approach. Nevertheless, a simplified approach using constant fluid temperature and convection heat transfer coefficient was used in this analysis and is sufficient to evaluate potential phenomena that are likely to occur in the system.

7.6.6.2 Descriptions of Numerical Models

Model Configurations

Three-dimensional models were employed in numerical simulation using a finite element computer program called "ANSYS". Figures 7.6-6 and 7.6-7 illustrate the model configuration and finite element meshes. A symmetric condition was assumed along two vertical cross-sections, one through the middle of the waste package and the other at the midpoint between two adjacent packages, so only half of a drift segment, 18.92 m in length, together with a half section of a waste package and a half section of the electronic and insulative boxes were modeled (Section 4.3.2.2). The closest distance from the outside surface of either the insulating box or electronics box to the waste package was 0.2 m. As shown in Table 7.6-3, seven different cases, identified as Case 1 through Case 7, are based on the variations of their boundary conditions and design considerations such as the presence or absence of insulation, internally generated heat, and simplified active cooling. It is noted that the model configuration shown in Figures 7.6-6 and 7.6-7 are for the cases 2 through 7, and a similar configuration for Case 1 may be produced by removing the insulating box from the model. Dimensions of the air gaps between the insulating and electronic boxes, as can be determined from the information in Table 4-2 of Section 4.3.3.5, vary from side to side, with a minimum of 0.01 m and a maximum of 0.49 m. Note: the "electronics box" is also referred to as the "device box".

Table 7.6-3. Thermal Modeling Cases and Descriptions

Case Identifier	Case Descriptions
Case 1	Electronics box, without insulation, internal heat or active cooling.
Case 2	With 10 mm of insulation, without internal heat and active cooling.
Case 3	With 50 mm of insulation, without internal heat and active cooling.
Case 4	With 10 mm of insulation and 100 watts of internal heat inside the electronics box, without active cooling (Section 4.3.3.3).
Case 5	With 10 mm of insulation and 400 watts of internal heat inside the electronics box, without active cooling (Section 4.3.3.3).
Case 6	With 10 mm of insulation, 400 watts of internal heat inside the electronics box and active cooling provided between the electronics and insulating boxes with an assumed Convective Heat Transfer Coefficient of 4.5 W/m ² ·K (Section 4.3.3.3 and 4.3.3.4).
Case 7	With 10 mm of insulation, 400 watts of internal heat inside the electronics box and active cooling provided between the electronics and insulating boxes with an assumed Convective Heat Transfer Coefficient of 12 W/m ² ·K (Section 4.3.3.3 and 4.3.3.4).

Initial Conditions

Initial temperature in both the electronics enclosure box and insulating box was assumed to be 26°C, based on the initially unaltered air and rock temperatures at the emplacement drift horizon. Initial temperatures on the waste package and drift wall surfaces were both assumed to be 200°C (Sections 4.3.3.1 and 4.3.3.2). Assumed thermal properties for the electronics and insulating boxes are provided in Section 4.3.3.4.

Boundary Conditions

Constant temperatures on both the waste package and drift wall surfaces were assumed and equal to 200°C. Based on thermal symmetry, both vertical cross-sectional boundaries were prescribed as adiabatic, or zero heat flow, boundaries.

As indicated in Attachment V, the interior surfaces of the device box were specified as heat flux boundaries with a value of 57.5 and 230.0 W/m² for the 100- and 400-watt cases, respectively. Interior surfaces of the insulating box and exterior surfaces of the electronics box were prescribed as convection boundaries with a fluid temperature of 0°C and a convection heat transfer coefficient of 4.5 W/m²·K for Case 6 and 12 W/m²·K for Case 7 (Section 4.3.3.4).

Modeling Approach

A transient approach was employed in numerical modeling for the thermal response during a remote monitoring operation. Time-dependent variations in the temperatures of the insulating and electronics boxes were modeled as a result of combined thermal radiation, convection and conduction. The models simulated the heat transfers: (1) from the hot waste package and drift surfaces to the relatively cool inspection gantry system and from the interior surfaces of the insulating box to the exterior of the electronics box by radiation; (2) from the internal heat sources to the electronics box by prescribing an equivalent heat flux on the interior surfaces of the box; and (3) between the surfaces of the insulating and electronics boxes and the cooling fluid by convection.

7.6.6.3 Results of Numerical Modeling

Numerical modeling for the thermal response during a remote monitoring operation in emplacement drifts was performed using the computer software ANSYS for the seven cases mentioned above. Results of the thermal modeling include time-histories of temperatures on the insulating and electronics boxes, and temperature distributions in the box media at a specified time during the operation.

Effects of Insulation, Internal Heat Generation and Active Cooling

Table 7.6-4 and the graph in Figure 7.6-10 summarize the results from numerical modeling for all seven cases studied. From Table 7.6-4 and Figure 7.6-10, three significant trends can be observed. First, the effect of insulation, second, the effect of internal heat sources, and third, the effect of active cooling.

Table 7.6-4 Results of Numerical Simulation for Seven Cases

Case Identifier	Time for Temperature to Reach 50°C at an Internal Surface of the Electronics Box (minutes)
Case 1	33
Case 2	67
Case 3	212
Case 4	64
Case 5	56
Case 6	184
Case 7	In 720 minutes the temperature increased only 1°C, to 27°C (Resident time effectively limited only by active cooling reservoirs)

Figure 7.6-10

Maximum Electronics Box Internal Temperature versus the Time of Exposure inside a 200 °C Emplacement Drift Environment

The effect of a variation in the amount of insulation material can be seen by comparing the results of Cases 1, 2 and 3. With all other parameters held constant, Case 1 has no insulation, Case 2 has 10 mm of insulation and Case 3 has 50 mm of insulation (Section 4.3.3.4). From Table 7.6-4 and Figure 7.6-10, it can be seen that adding 10 mm of insulation increases resident time by about 103%, to 67 minutes (resident time is defined as the amount of time that given electronics device could be operated inside a 200°C emplacement drifts before temperatures inside its electronics box begin to exceed the threshold of 50°C.). Increasing the insulation material to a thickness of 50 mm increases the resident time about 542%, to 212 minutes. Therefore, as can be anticipated, the amount of insulation material used has a dramatic impact on the heat rejection characteristics of the thermal design model. It appears from this preliminary examination that even 50 mm of insulation could provide sufficient insulative capacity for the Remote Inspection Gantry.

The effect of introducing a heat source inside the electronic box can be observed by comparing Cases 2, 4, and 5 as indicated in Table 7.6-4 and Figure 7.6-10. The internal heat sources represent the heat that may be generated by the electronic devices housed within the electronics box. With only 10 mm of insulation and all other parameters held constant, Case 2 is a reference case with no internal heat, Case 4 has a 100 Watt internal heat source, and Case 5 has a 400 Watt internal heat source. By introducing the 100 Watt heat source in Case 4, the resident time is reduced only about 4%, to 64 minutes. By introducing the 400 Watt heat source in Case 5, the resident time is reduced only about 16%, to 56 minutes. This would suggest that internal heat sources within the ranges expected for the Remote Inspection Gantry may only have a moderate effect on resident time.

The effect of introducing a source of active cooling in between the electronics and insulation boxes can be observed by comparing Cases 5, 6, and 7 as indicated in Table 7.6-4 and Figure 7.6-10. With 10 mm of insulation, 400 Watts of internally generated heat, and no active cooling, Case 5 can be used as a reference case. With all other parameters held constant, Case 6 depicts the results of introducing an active cooling source with a Convective Heat Transfer Coefficient of 4.5 W/m²·K and Case 7 depicts the results of introducing an active cooling source with a Convective Heat Transfer Coefficient of 12 W/m²·K. Both 4.5 and 12 W/m²·K are considered conservative estimates for active cooling. From Table 7.6-4 and Figure 7.6-10, it can be seen that providing an active cooling source as indicated in Case 6 produces a significant increase in resident time with a 128 minute increase (229%) over Case 5. Case 7 demonstrates that it may be possible to provide an active cooling source that enables the electronics boxes on board the Remote Inspection Gantry to operate at approximately room temperature. Over a period of 720 minutes, the thermal model being evaluated increased in temperature by only 1°C to 27°C. In essence, this means that the in-drift resident time may only be limited by the size of on-board reservoirs of cooling fluids.

In summary, it appears that thermal insulation and active cooling are effective means for reducing the radiant heat on the electronic devices and prevent them from malfunctioning due to overheating. Active cooling may substantially increase the time allowed to perform the remote monitoring in

emplacement drifts, and would be worthwhile to consider as part of the thermal control system design. Additional analysis will be possible once more detailed requirements are imposed that establish the specific monitoring functions required in an emplacement drift. These detailed requirements will allow calculations to be performed that determine the amount of in-drift time required to perform the monitoring functions, with a resulting determination of the amount of cooling necessary.

7.6.7 Remote Inspection Gantry: Radiation Shielding

This section provides an initial examination of issues related to the radiation shielding needs of the proposed Remote Inspection Gantry. As discussed here, and in a prior analysis (Reference 5.7), protecting sensitive electronic components from the adverse effects of radiation is a primary area of interest to the design. The amount of radiation shielding required will depend on the particular components to be selected. For some components no added shielding will be required, while other components may need extensive shielding that reduces radiation to acceptable levels. Since this analysis is early in the design process and well in advance of component selection, it will be helpful to examine generic cases, or design scenarios, that approximate conditions that may be encountered within the active emplacement drifts. Design calculations and estimates associated with this section are contained in Attachment IV. The general design scenarios considered in this section include, minimal, nominal, and maximum levels of shielding. The radiation levels associated with off-normal conditions are presented and discussed in Attachment IV.

As discussed in Reference 5.7, the use of radiation-hardened components or other design strategies, such as the periodic replacement of electronic components based on cumulative dose exposure levels, may allow components to operate within the active emplacement drifts with only minimal levels of shielding. See the above cited reference for additional information. For the purpose of this analysis, "minimal shielding" may consist of little more than a thin-walled metal enclosure.

For initial evaluation of mass and thermal design issues in other sections of this analysis a "nominal shielding" case was used. For the rough order-of-magnitude estimates within this analysis, nominal shielding is considered to be approximately mid-way between the minimal and maximum cases. Radiation shielding calculations and estimates in Attachment IV address the minimum and maximum cases but not specifically the nominal case.

In this initial assessment on radiation shielding needs an effort is made to examine the extreme case where a maximum level of radiation shielding may be needed to protect a particular component. At this stage of the design it is not certain which, if any, components would require this level of shielding, nevertheless, for evaluation purposes, it is assumed that a sensitive component, such as a commercial-grade microprocessor might be used and would require extensive shielding for protection.

For normal operations, the Remote Inspection Gantry will be exposed to a mixed radiation field of neutrons and gammas from intact waste packages (WP) emplaced in the drifts (Section 4.1.1, 4.1.2, and 4.3.4). The containment barriers including inner and outer barriers of the waste packages provide some shielding to reduce radiation levels to less than 100 Rem/hr (Section 4.3.4.4) at the waste package surface. Within the structure of the Remote Inspection Gantry there will be metal box enclosures, or "electronics boxes" containing the essential microprocessors and electronic circuits needed to operate the gantry. Depending on design layout, as shown in Figure 7.6-4, these electronic boxes may be located in relatively close proximity to the radioactive waste packages with distance ranging from 280 to 760 mm away from the waste package surface. This distance will result in a slight reduction in the dose rate due to physical separation.

The above radiation fields are expressed in units of Rem/hr for human exposures. For evaluation of radiation effects on semiconductors and electronic components, the dose rates will be calculated in terms of absorbed energy deposition in silicon expressed as rad(Si)/hr, which is the common term used for electronic systems. For gammas which have a quality factor of 1 for biological effects, 1 rad/hr is close to 1 Rem/hr (Reference 5.37). However, 1 rad/hr in silicon is considerably less than 1 Rem/hr for neutrons, since the quality factors for neutrons are 1 or greater depending on neutron energy. The assumed dose rate of 100 Rem/hr at the waste package surface is mainly from gammas. The neutron dose contribution is negligible as compared with the gamma contribution. Therefore, the value of 100 Rem/hr is approximately equal to 100 rad/hr.

The radiation environment to which the Remote Inspection Gantry will be subjected was determined. Initial focus was placed on the waste package containing 21 PWR spent fuel assemblies, each with 4.2% initial enrichment, 48,086 MWD/MTU burnup (where MWD stands for Megawatt-days, and MTU stands for Metric Tons of Uranium) and 10 years decay as design basis fuel (DBF) (Section 4.3.4.1). Similar or comparable radiation fields are expected for waste packages containing Boiling Water Reactor (BWR) spent fuel assemblies and Defense High-Level Waste (DHLW). Radiation fields were estimated at the two extreme locations of the electronic box, namely, 280 to 760 mm radially from the maximum waste package envelope (2 m, outside diameter) (Sections 4.3.2.2 and 4.3.2.9). With the use of the assumed 100 rad/hr at the waste package surface as a normalization factor, estimates with the qualified MCNP4A code (Section 6.2 and Reference 5.28) indicate that the radiation fields are 62 rad/hr at 280 mm, and 48 rad/hr at 760 mm from the intact waste package surface.

7.6.7.1 Radiation Effects on Electronic Components

The primary radiation effect on semiconductor circuits and electronic devices is ionization damage resulting from electron-hole pairs within the gate and field oxides of semiconductor structures produced by ionizing radiation (Reference 5.12). Some of the ion pairs may recombine with no

effect on circuit function. However, the electrons from ionization have high mobility in the oxide and are quickly swept out by internal fields. The holes have much lower mobility. Some fraction of the holes will migrate to the silicon/silicon-dioxide interface, where they will be trapped. The trapped charge increases with continued irradiation, and can change the threshold voltage and mobility of the gate and field-oxide transistors, modifying their characteristics. After extended exposure to high levels of radiation, these effects ultimately can cause device failure.

According to Reference 5.12, many commercial integrated circuits can be used safely without qualification, if the dose rate of ionizing radiation is less than 1 rad(Si)/hr and the total uninterrupted exposure to radiation does not exceed 5,000 hr [i.e., total dose of 5,000 rad(Si)]. Radiation-hardened circuits will be required for applications where the dose rate is above 1,000 rad(Si)/hr. Reference 5.12 recommends that the available radiation-hardened microprocessor families be chosen for future robotics designs irrespective of the radiation dose rate.

Design options are available to minimize or prevent adverse radiation effects on electronics. One option is to provide radiation shielding for the electronic box which houses the required microprocessors, circuits and sensors to reduce the dose rate to less than 1 rad(Si)/hr inside the box. Use of shielding may extend the useful life of the electronic components. Another option is to use radiation-hardened electronic components with a total radiation tolerance of 10^5 to 10^6 rad(Si). The latter option will eliminate the need for shielding, but will limit the useful life of the components depending on the radiation condition.

7.6.7.2 Estimate of Shielding Needs For Radiation Sensitive Electronics

The electronic components used on the Remote Inspection Gantry will be in a radiation environment approaching 100 rad(Si)/hr for normal conditions. This level far exceeds the recommended limit for some sensitive off-the-shelf commercial electronic devices of 1 rad(Si)/hr. This section of the analysis estimates the maximum level of radiation shielding that would be needed if sensitive commercial electronic components are used and radiation levels were reduced to acceptable levels.

The principal contributor to the dose rate outside the waste package is gamma radiation from spent nuclear fuel assemblies (Reference 5.29). The neutron dose in Rem/hr is relatively small (less than 10% of the total). The neutron contribution becomes negligible when expressed in units of rad(Si)/hr. For radiation shielding, steel appears to be the best choice to shield the electronic box, in view of its reasonably high density for gamma shielding, low cost, and ease of construction. The one-tenth value for steel, defined as the material thickness required to reduce the gamma dose rate by a factor of 10, is about 50 to 64 mm, depending on the gamma energy spectrum.

The thermal analysis in Section 7.6.6 and radiation shielding evaluation in Section 7.6.7 indicate that basic design of the Remote Inspection Gantry could support the use of primarily off-the-shelf, commercially available parts, thereby keeping costs down.

Today the procurement of one commercially available gantry crane, pre-approved by the NRC to handle radioactive waste canisters weighing under 5 tons, costs approximately \$1M.

Noting the similarities and differences cited above, it is reasonable to assume that the base vehicle of the proposed Remote Inspection Gantry should not exceed the cost of the commercially available gantry crane. Based on the originator's experience with prior related design, fabrication and integration tasks (Reference 5.38), the costs associated with add-on instrumentation packages, such as the Remote Inspection Gantry's camera system (approximately \$200K), thermal and IR camera system (approximately \$200K), and the remote manipulating system (approximately \$250K), along with the cost of the surface-base control station interfaces (approximately \$150K) and additional software development costs (approximately \$500K), and the costs associated with extensive reliability testing (approximately \$1M), the overall project costs could amount to roughly \$3.3M.

7.6.9 Remote Inspection Gantry: Design Summary

Section 7.6 has presented a preliminary conceptual design for a Remote Inspection Gantry that can be considered for Viability Assessment (VA) design purposes. The Remote Inspection Gantry is a mobile remote inspection system that can be deployed within emplacement drifts containing waste packages and provide real-time visual, thermal, radiological and environmental monitoring information.

Initial evaluations (Attachment I) indicate that with a top vehicle speed of 10 km/hr (Section 4.3.2.10), the Remote Inspection Gantry could perform a non-stop survey of a selected drift in approximately 10 minutes and a multiple stop inspection in approximately 70 minutes. This compares favorably with the preliminary thermal analysis in Section 7.6.6 that indicates with only minimal thermal insulation and conventional thermal control techniques (e.g. active cooling), the Remote Inspection Gantry may be able to operate inside 200°C emplacement drifts for extended periods of time before internal gantry temperatures exceed acceptable levels for commercial grade electronics (i.e. 50 °C).

Initial rough order-of-magnitude power estimates in Attachment I indicate the power requirements are within achievable ranges. The thermal analysis in Section 7.6.6 indicates that there appears to be sufficient thermal capacity within the system design to dissipate the levels of internally generated heated anticipated from the use of electric power.

With the assumption of a bounding normal radiation field of 100 rad/hr in the emplacement drifts (Reference 4.3.4.4), an analysis with the qualified MCNP4A code confirms that a Type 304 stainless steel thickness of 102 mm is adequate to reduce the dose rate at the location of the nearest electronic box to about 1 rad/hr for normal operating conditions, i.e. the waste packages remain intact. Other types of steel with similar density may be used. Listing of the computer input and output for this analysis is provided in Attachment IV. This amount of shielding would be needed on the sides facing the waste packages. Shielding for the back side facing the drift wall may be reduced to 51 mm, which is needed to attenuate scattered radiation from the drift wall.

At this stage in the design process it is sufficient to note that several factors may influence the selection of the design option, including emplacement drift conditions, amount of shielding required, cost and availability of radiation-hardened components, and operational requirements. These factors are not currently addressed within the scope of this initial analysis but should be considered in future analyses.

7.6.8 Remote Inspection Gantry: Cost Comparison

Cost is an important issue to consider in design. An otherwise effective design can be rendered non-viable if the associated costs are too high. The purpose of this section is to begin to explore the costs associated with developing and implementing a system like the Remote Inspection Gantry. Presently, there is not enough design detail to make an accurate assessment of the costs; however, it will be helpful to discuss approximate, rough order-of-magnitude (ROM) figures that may give an indication of the feasibility of the concept.

For rough cost estimating purposes, a reasonable cost comparison can be made between the proposed Remote Inspection Gantry and commercially available gantry cranes which are approved by the NRC and used in the nuclear industry (See Attachment III). There are significant similarities, namely, they both are technologically similar in complexity, both are based on PLC technology, both devices travel on a rail system, have one degree-of-freedom for motion control, are remotely controllable and are required to have ultra-reliable fail-safe drive and braking systems. Another similarity is that the commercially available gantry crane is now NRC approved as will the inspection gantry need to be in the future. There are differences as well, such as, the commercial gantry cranes are typically many times larger and more massive than the proposed Remote Inspection Gantry, and commercial gantry cranes are designed to lift large multiple ton loads, while the proposed Remote Inspection Gantry will not need to lift large loads. Both of these differences would tend to cause the commercially available gantry crane to be more expensive than the proposed inspection gantry. However, the inspection gantry will need to operate in a more hostile thermal environment, travel greater distances and will be equipped with add-on instrumentation packages that are not included in the price of the commercially available gantry crane.

A preliminary radiation shielding analysis presented in Section 7.6.7 indicates that even if sensitive, off-the-shelf, commercial-grade, electronic components are used, it is feasible to provide enough shielding to reduce radiation levels to acceptable levels.

Preliminary concepts for remotely communicating with, and supplying power to, the inspection vehicle appear technologically feasible.

As technology advances, the modular design of the remote inspection system design will facilitate periodic improvement and upgrade to the basic system capabilities and technologies, thereby optimizing system utility and effectiveness and preventing system obsolescence.

7.7 Monitoring Observation and Perimeter Drift Borehole Instrumentation

As discussed in section 7.5, if it is desired to obtain altered zone data using in-situ instrumentation, access to the instruments must be maintained for repair and calibration. (Note: the term altered zone refers to data obtained from the geologic region affected thermomechanically by waste package emplacement, and is discussed further in the PCCSR, Reference 5.5). The placement of instrumentation within the emplacement drifts requires additional design effort and investigation. Another concept that can be utilized for acquisition of this altered zone data involves the drilling of boreholes from non-emplacement areas into the altered zone surrounding the emplacement drifts. Observation drifts (ODs) will be excavated to serve as the primary locations from which the boreholes could be drilled, and their instrumentation installed and maintained. The number, layout and configuration of the observation drifts are the subject of a separate analysis (Reference 5.6).

There is a wide variety of instrumentation available for the required monitoring applications. This section will provide discussion of the types of data required and the types of instrumentation that could be utilized.

7.7.1 Parameters to be Monitored

The source for the development of the following list of parameters is Table D-1, "Key Performance Confirmation Parameters for Design" of the "Performance Confirmation Concept Study Report" (Reference 5.5):

- ◆ Air Permeability
- ◆ In-situ Rock Stress
- ◆ Rock Strain
- ◆ Rock Deformation and Displacement
- ◆ Soil and Rock Temperature
- ◆ In-situ Fluid Potential
- ◆ Altered Zone Moisture Content
- ◆ Altered Zone Water Vapor Content/Humidity
- ◆ Fluid Temperature
- ◆ Air Pressure

Sources have been used for guidance, with the objective being to produce a list of measurable parameters, but not to list all derivative parameters or properties that can be obtained from the measurable parameters. For example, the measurement of thermal conductivity may be important to know for performance confirmation purposes, however, this property is determined from temperature measurements (by RTD, thermocouple) at various locations. In this case, therefore, temperature is the basic parameter to be measured, not thermal conductivity.

7.7.2 Instrumentation for Borehole Monitoring

Although the location for monitoring instruments and methods discussed in this section are primarily observation drifts and boreholes drilled from observation drifts, monitoring boreholes could also be drilled from the main access drifts and from cross block ventilation drifts. These drifts could be used for instrument installation and monitoring, just as an observation drift could be used. For the VA design the use of main drifts and ventilation drifts for the location of borehole instrumentation should not be used because of the operational interference that could result. This option is held in reserve and may be used to address specific data needs that may be identified during the construction and operation of the facility. If deemed necessary by the PC program, test alcoves could be constructed from the main access drifts and from cross block ventilation drifts to facilitate the collection of data.

Tables 7.7-1 and 7.7-2 list parameters to be obtained by means of observation drift and test alcove borehole monitoring. These parameters do not constitute a complete or final list but are considered representative of the thermal, mechanical, hydrological, and chemical characteristics that need to be monitored for performance confirmation. For each parameter, an instrument type is given to illustrate a reasonable measurement approach. The source for the development of the list of instruments is Table 1-4, "Listing of Parameters and Corresponding Instrumentation" in "Test Design, Plans and Layout Report for the ESF Thermal Test" (Reference 5.16). Although design values (e.g., ranges for temperature, displacement, and moisture) have not been established for specific instruments, a typical instrument, if known, is listed. In addition, the instrument's stated operating range and output are given to provide information for the planning of the data acquisition system. In many cases, even if a typical instrument is cited, some modification or new development would likely be necessary to fulfill the purposes of performance confirmation monitoring. For example, consideration will need to be given to requirements for longevity and whether an instrument needs to be replaceable or to be designed as a probe rather than as a permanent installation.

Operating temperatures, i.e., rock and air temperatures, are expected to be the most important constraint on instrumentation installed in the vicinity of the repository horizon. For example, temperatures of the rock mass may range from ambient to an allowable upper limit of 200°C (DCSS 023, Section 4.3.1). Observation drift air temperatures may range from 27°C (effective) to an allowable limit of 50°C (dry bulb) (Section 4.3.2.3).

7.7.2.1 Deformation/Stress

Rock mass deformation will occur as a result of temperature change, with significant increases in horizontal rock stress occurring in the plane of the repository and locally high tangential stress developing around emplacement drifts (Reference 5.18). Concurrently, thermally-induced deformation of the repository block will result in upward movement of the ground surface. Drift stability is directly related to rock mass movements, the prediction of which is an important part of the thermomechanical design analyses for the repository. Both heating and cooling of the emplacement drifts are expected to have measurable effects on the rock mass.

Measurement by means of a vibrating wire stress meter allows a determination of the thermally-induced rock stress change over a relatively small volume of rock surrounding a borehole. Measurements of rock mass displacement over tens of meters of rock by a MPBX (multi-point borehole extensometer) can be used with temperature measurements to determine rock mass thermal expansion or the effects of drift convergence if in the vicinity of an emplacement drift (Reference 5.18). Large-scale repository block deformation can be monitored by direct measurement of changes in observation drift alignment and grade using appropriate engineering surveying techniques.

Table 7.7-1 Typical Instruments for Observation Drift and Borehole Monitoring

Parameter	Location	Instrument Type	Example Instrument/ Manufacturer*	Example Temperature Range*	Example Instrument Output*
Deformation/Stress					
Strain/stress change at a point	Borehole	Vibrating wire stress meter	Geokon	-30 to 65 C	400 to 6000 Hz
Rock mass displacement	Borehole	MPBX (multi-point borehole extensometer)	Geokon	-20 to 80 C	400 to 6000 Hz
		Deflectometer / In-place inclinometer	Geokon	-20 to 50 C	-5 to 5 V
Temperature					
Air temperature (dry and wet bulb)	Observation drift	Humidity sensor	Vaisala HMP 235	-40 to 180 C	0 to 5 V
Rock temperature	Borehole	Thermocouple	Pyromation Type K	-270 to 1372 C	-6 to 55 mV
		RTD	Watlow Gordon 4 - wire	-200 to 650 C	1000 ohm
		Rapid Evaluation of K and Alpha-Thermal Probes (REKA)	UNR	0 to 260 C	0 to 5 mV (approx.)

* This information and numerical values are preliminary, to show examples of typical existing instrumentation and do not necessarily match the design needs for a given installation.

Table 7.7-2 Typical Instruments for Observation Drift and Borehole Monitoring

Parameter	Location	Instrument Type	Example Instrument/ Manufacturer*	Example Temperature Range*	Example Instrument Output*
Moisture					
Rock moisture	Borehole	Humidity sensor Neutron logging ERT (electrical resistivity tomography)	Vaisala HMP 235 Century Geophysical Advanced Geosciences	-40 to 180C up to 105 C up to 150 C	0 to 5 V Digital counts 400 to 800 V
Relative Humidity/dry bulb air temperature	Observation drift	Humidity sensor	Vaisala HMP 235	-40 to 180 C	0 to 5 V
Rock pore air pressure	Borehole	Air-K testing with packer system	SEAMIST system with pressure transducer	up to 160 C	300 mV to 5 V
Chemistry					
Water chemistry/mineralogic changes	Borehole	Borehole chemical sensor and fluid sampling	SEAMIST system with chemical sensors	up to 160 C	0 to 5 VAC

* This information and numerical values are preliminary, to show examples of typical existing instrumentation and do not necessarily match the design needs for a given installation.

7.7.2.2 Temperature

Temperature is a fundamental parameter to be monitored because heating from nuclear waste decay is expected to disturb the rock mass mechanically, hydrologically, and chemically. Properties that can be derived from temperature measurements include heat capacity (specific heat) and thermal conductivity. Examination of certain phenomena, such as propagation of a "drying front", drainage/reflux of liquid by fracture flow, and conductive/convective heat transfer, require temperature monitoring. Air temperatures are important indicators of waste package performance and heat transfer through the rock. Accurate measurement of other parameters, e.g., rock deformation, depends on the monitoring of temperature.

Instruments for temperature measurement include thermocouples, RTDs, and REKA (rapid evaluation of k and alpha-thermal probes) (Reference 5.16).

7.7.2.3 Moisture

The quantity and rate of movement of moisture through the rock mass in response to heating are important parameters in understanding hydrologic processes that affect long-term repository performance. Specific parameters needed for hydrologic interpretations include rock moisture, air humidity, and air pressure. Phenomena that can be derived using the measured moisture parameters include (Reference 5.18):

- Conductive/convective heat transfer
- Changes in rock saturation
- Propagation of "drying front"
- Drainage/reflux of liquid by fracture flow
- Rock mass and fracture permeability changes

Instruments include humidity sensors, neutron logging or ERT (electrical resistivity tomography) methods.

7.7.2.5 Chemistry

Measurement of water chemistry with time and temperature is also needed to determine any changes, especially interactions between the natural environment and introduced materials such as the waste packages and drift linings. Techniques for determination of in situ chemistry include borehole chemical sensors and fluid sampling.

7.7.3 Borehole Monitoring Data Transmission

This section of the analysis will discuss how the data measured by the sensors in section 7.7.2 can be recorded, how the wiring may be routed, and how the data may be acquired by the PC system.

Refer to Figures 7.7-1 and 7.7-2 for a possible scenario for observation drift borehole monitoring. From the figures, it can be seen that numerous boreholes could be drilled from alcoves which extend both North and South off of the observation drifts, which, in this alternative, are constructed parallel to the emplacement drifts. The alcoves remove the instrumentation from the main haulage way of the observation drift which should reduce the disruption of testing activities and other operations. The first observation drift can be excavated during the pre-emplacement development period so that it can be ready to begin data acquisition with the emplacement of the first waste packages. Subsequent observation drifts can be constructed during the normal development operations.

This concept resembles the current plans for the ESF thermal test where the heated drift is not accessible, but is monitored via borehole instruments. Selected boreholes could penetrate the emplacement drift wall, if deemed appropriate, allowing instrumentation to be inserted directly into the emplacement drift, and then withdrawn. Instrumentation can be installed in the boreholes from the observation drifts, and if repair or re-calibration is needed, they can be removed and reinserted from the observation drift. In the case of instruments that must be grouted in place, additional holes can be drilled in the event of an instrument failure.

Thermal, mechanical, hydrological, and chemical instruments can all be installed in one borehole to provide the required information. The quantity of sensors to be installed in a borehole determines the resulting borehole diameter. The diameter is a result of the physical aspects of the equipment to be mounted in the borehole, such as wire size and quantity of devices. Boreholes containing larger sensory equipment, such as MPBX transmission devices, will accommodate fewer channels than boreholes which contain small devices such as temperature and humidity sensors. This analysis will size the data acquisition system by using the quantity of thirty-five channels originating from each borehole (Section 4.3.2.6). The final quantities and types of transmission equipment to be installed in each borehole will be developed as the performance confirmation design progresses. This exercise is intended to demonstrate the viability of a performance confirmation data acquisition system. As stated earlier, data acquisition system equipment by its modular nature is extremely versatile and can be assembled to accommodate almost any possible measurement requirement in numerous ways.

FIGURE 7.7-2
OBSERVATION DRIFT MONITORING
DATA ACQUISITION

Refer to Figure 7.7-2. If there are thirty-five channels originating from each borehole, the North alcove will have a total of 210 input channels to the data acquisition system and the South alcove will have a total of 245 input channels (Section 4.3.2.7). This results in a total of 455 input channels per alcove arrangement off of the observation drift. It is anticipated that there will be ten alcove arrangements off of each observation drift as shown in Figure 7.7-3. The number of signals for each observation drift is therefore 4,550 (10 x 455). By adding approximately 20 % for spares and design contingencies the number of channels for each observation drift is increased to 5500. Refer to table 7.7-1 for a relationship of percent of repository coverage versus the quantity of observation drifts and resulting quantity of input signals. The quantity of observation drifts is not yet determined and table 7.7-1 is provided to give a rough order-of-magnitude of the quantity of signals that may ultimately be required.

Table 7.7-1

% of Total Number of Emplacement Drifts Monitored	Quantity of Observation Drifts	Quantity of Input Signals
4 %	1	5,500
20 %	5	27,500
53 %	13	71,500
100 %	25	137,500

If there are five observation drifts, (Section 4.3.2.8) then the total number of inputs to the data acquisition system from observation drift borehole monitoring can be 27,500. If the quantity of observation drifts increases, then the quantity of data acquisition input signals will increase accordingly.

The wiring for each signal from the boreholes will exit the borehole in either the North or South alcove off of the observation drift. It is in these alcoves that the acquisition hardware should also reside. The data acquisition hardware which will reside relatively close to the borehole signal transmission devices will consist of a controller board, I/O card racks, I/O cards, and cables which connect the I/O card racks to the controller board. The following discussion will present one observation drift borehole monitoring data acquisition network to show the viability of such a system, based on utilizing five observation drifts. Additional effort will be required to arrive at the most optimal installation from a cost, installation, and maintainability standpoint.

PLAN - OBSERVATION DRIFT LAYOUT

LEGEND:

- CONTROLLER BOARD ENCLOSURE
- ▼ I/O RACK ENCLOSURE

FIGURE 7.7-3
OBSERVATION DRIFT MONITORING
SYSTEM LAYOUT

There will be 210 channels required in the North alcove and 245 channels required in the South alcove. In the North alcove 210 channels can be accommodated by fourteen - sixteen channel input cards. Adding three cards for spares and design contingencies brings the total number of cards for the North alcove to seventeen. This quantity of cards can be housed in two I/O card rack assemblies which can typically house 4, 8, 12 or 16 cards (Reference 5.19).

The I/O rack cannot communicate with higher level process equipment and therefore requires connection to a controller board. The controller board enclosure can be mounted in the South alcove and the controller board could be mounted in the same enclosure that contains the South alcove I/O card rack. Because the controller board will interface with other controller boards and the main performance confirmation computer system, it can also be mounted near the observation drift which can contain the communication backbone. Two hundred forty five channels, for the South alcove I/O, can be accommodated by sixteen - sixteen channel input cards. Adding four cards for spares and design contingencies brings the total number of cards for the South alcove to twenty. This quantity of cards can be housed in two I/O card rack assemblies.

For the above example, one controller board will be located in each alcove arrangement of the observation drift. The distance between each alcove arrangement, and therefore, each controller board, will be roughly 100 meters. To facilitate communication between each controller board and performance confirmation computer(s) on the surface, a fiber optic trunk line or backbone should be installed down the length of the observation drift. For a discussion of the fiber optic transmission medium, see Section 7.4.4. This fiber optic cable could be routed down the length of the observation drift, down the observation drift exhaust raise to the exhaust main where it can tie into the fiber optic cable running down the exhaust main. The signals would then be available for surface monitoring, trending, alarming and storage.

The above discussion presents a viable method for the observation drift borehole monitoring data acquisition network for performance confirmation. A fiber optic trunk line can be run down the observation drift and can be connected to controller boards which in turn can be connected to I/O racks which in turn can be connected to I/O cards which in turn can be wired to the instruments mounted in the boreholes as shown in Figure 7.7-4. The fiber optic trunk line would be routed to the exhaust main where it can tie into the exhaust main fiber optic line. Sufficient spare input capability exists to accommodate the design as it progresses. Thermistors can be installed in each data acquisition enclosure to monitor the temperature and alarm if it approaches 50 °C, which is the upper operating limit for most acquisition hardware. The diversity of the acquisition hardware can not be stressed enough. Once the trunk line or communication backbone is installed, it is a matter of connecting the required hardware.

FIGURE 7.7-4
SCHEMATIC BLOCK DIAGRAM
OBSERVATION DRIFT MONITORING

7.8 Performance Confirmation Subsurface Data Acquisition Network

This section will present an overview of the PC data acquisition network. It will discuss how the data may be handled, presented, stored and displayed to the operator. An estimate of the total system Input/Output (I/O) requirements will also be discussed.

7.8.1 Network Overview

A network can be defined as a collection of communicating devices that are interconnected and autonomous (Reference 5.17). All of the following conditions are essential for a functional network:

- ◆ A communicating device is any system that transmits or receives data. A communicating device can be a mainframe, personal computer, modem, controller board, or telephone.
- ◆ The interconnection of devices asserts that this equipment can exchange data. The interconnection may be over some physical medium, such as optical fiber, or through the air via radio waves or lasers.
- ◆ The devices on the network are autonomous, or "crash independent". That is, failure of a single device does not cause other devices to become inoperable and bring down the entire network.

The equipment required for the acquisition of data for performance confirmation will be incorporated in the repository network in a manner incorporating the above features. The controller boards will all be interconnected via fiber optic cable. The particular topology of the network requires further investigation and design effort. Brief discussions of the various topologies follow.

In a star topology (Reference 5.17, 5.23), all devices on the network are interconnected through a central node. All communication is from one device to another; the central node acts only as a switch to provide a pathway between pairs of devices attached to it. A good example of a star network is a telephone switchboard, since access from one station on the network can occur only through the central device. The central node does pose high single point of failure concerns. This topology does not appear to be well suited for the repository application.

In a bus topology (Reference 5.17, 5.23), a cable is usually laid out as one long branch onto which smaller branches are used to interconnect each station to the main data highway. Bus networks can be compared to the way appliances in the home are connected to the AC power line. Buses are probably one of the oldest network topologies. Buses are usually limited in the communicating medium that they can use, but do not typically suffer from single point failure problems.

In a ring topology, the communicating devices are connected by a set of point-to-point links that are organized in a closed fashion. Rings are commonly employed in networks. If one link of the ring is cut or disconnected, the entire network remains on-line. This is because the communications can reverse directions in the circular ring. The communications software can even locate the point where the disconnection or break has occurred.

Some networks are a mixture of topologies. Because of the inherent reliability and reduced single failure potential of a mixture, that is how the repository network will eventually be constructed. A redundant ring can be installed around the perimeter of the repository such as down the North main, then down the East main, over to the West main and eventually back out the North ramp to the surface facilities. Off of this redundant ring can be other smaller redundant rings such as down the exhaust main and the South ramp. Off of the exhaust main, branches could be run up to the observation drifts and the associated data acquisition equipment located therein. The entire aspect for the proper network to be installed in the repository requires additional design effort and investigation. Refer to figure 7.8-1 for a depiction of the interconnection of the performance confirmation data acquisition devices.

7.8.2 Operator Interfaces and Control Stations

All of the devices for transmission of performance confirmation data will be networked together and will allow personnel on the surface to view and manage this information. It is anticipated that the performance confirmation control center will consist of a control room from which all subsurface data acquisition systems can be monitored. This control room will be equipped with engineering workstations, mainframes, control consoles and graphics terminals that can provide the operators with direct real-time data. Sufficient storage capacity should exist for time-stamping the data as it is received. This data can then be periodically plotted out to provide information from which accurate interpretations regarding the repository environment can be made.

The network can be installed with sufficient access points to allow an authorized individual to temporarily hook up a lap top or notebook computer underground and have access to the transmitted data. Versatility, accuracy, timeliness, and robustness are all attributes that can be implemented in the performance confirmation data acquisition system.

FIGURE 7.8 - 1
SUBSURFACE DATA ACQUISITION NETWORK
FOR PERFORMANCE CONFIRMATION

7.8.3 Estimated Size and Complexity

From the information stated previously, there can be approximately 1,200 points from the exhaust monitoring system, approximately 200 points from the mobile remotely controlled inspection system, and approximately 27,500 points from the observation drift monitoring system. Allowing a design contingency of 6,100 points for additional perimeter, empty emplacement drift borehole and test alcove monitoring brings the total number of inputs to 35,000. It is worth noting that the sample rate for these points may range from once a day, to once an hour, to once every fifteen minutes, to continuous monitoring. In other words all 35,000 points will not be continuously updated; if they were it could cause high volumes of network traffic.

The fiber optic backbone which may be installed in the repository could operate up to and in excess of 150 million bits/sec (Mbps). (Reference 5.17) However, the software must be configured to handle this high data rate. Assume that the network can handle a more conservative data rate of 100 Mbps. Analog values are usually converted to digital signals in 12 or 16 bit resolution. If the data rate of the network (100 Mbps) is divided by 120 bits, which could be representative of one analog value with start delimiter, addressing, and end delimiters, the network can support transmitting over 800,000 analog values every second. Performance confirmation has roughly 35,000 points and repository operations will have numerous points, but the total will undoubtedly be less than 800,000. It is therefore highly doubtful that the network will become saturated and data could become lost or not updated in a timely manner. Faster network speeds will only increase the number of points available for transmission.

7.9 System Reliability, Availability, and Maintainability (RAM)

As the design concepts for the Performance Confirmation data acquisition system (PC DAS) evolve and mature it will be important to thoroughly evaluate the system's reliability, availability, and maintainability. A formal, in-depth, "RAM analysis" of the Performance Confirmation data acquisition system is by itself an extensive analytical undertaking and is outside the scope of this document. However, because of the importance of this topic to the overall success of the design and implementation, this section will begin to identify and outline RAM issues related to the PC DAS.

A RAM analysis of data acquisition systems for Performance Confirmation will assess the probability of success for various design concepts as the design evolves. Expressions for reliability or availability, where appropriate, will estimate the probability of the system being operable for intended service periods and environments. Usually, analysis works in "failure space" to assess the probability of failure or unavailability of each subsystem of the inspection system in the inspection environment (e.g., taking into account the levels of radiation, temperature, humidity, and dust) during defined mission duration. For example, one mission time is the cycle time for the entry - to -exit of the inspection gantry in each emplacement drift. Another mission time might be the time between planned refurbishment of one inspection module (e.g., video camera).

7.9.1 Reliability/Availability Analysis

Quantitative system reliability and availability analyses are performed to estimate the probability of mission success and to enable quantitative trade-off evaluations of alternative designs and operations as well as alternatives for test and maintenance. This subsection illustrates some of the fundamental relationships that affect system reliability and availability.

The most often used basis for system reliability modeling is the exponential model for time to failure. In the exponential model, the reliability of a component is expressed as (Reference 5.24, p. X-20):

$$R(t) = \exp(-\lambda t) \quad (7.9-1)$$

where

$R(t)$ is the probability that the component is functioning properly from time 0 through time t ,

t is the mission time, and

λ is the failure rate (number of failures per unit time) of the component.

The exponential model can be applied also to the subsystem and system levels with appropriate definitions of failure rate for the assembly.

Analysis is often more convenient by using the unreliability, or failure probability, given as (Reference 5.24, pg X-20):

$$F(t) = 1 - \exp(-\lambda t) \quad (7.9-2)$$

where

$F(t)$ is the probability that the component does not function properly (or fails to survive) at least until time t , and other terms are the same as above.

For non-repairable components, the unavailability is equal to the unreliability. An important characteristic of the exponential distribution is that the Mean-Time-Between Failures (MTBF) is the inverse of the failure rate (Reference 5.13, pg 7-4). For example:

$$\lambda = 1/\text{MTBF} \quad (7.9-3)$$

MTBF is an often-used parameter that may be included in equipment design, advertising, or purchase documentation. Using expression (7.9-3) in equation (7.9-2), the expression for unavailability for non-repairable failures is defined as (Reference 5.24, p XI-11):

$$Q_N(t) = F(t) = 1 - \exp(-\lambda t) \quad (7.9-4a)$$

or by substituting equation 7.9-3 into 7.9-4a it is derived that:

$$Q_N(t) = 1 - \exp(-t/\text{MTBF}) \quad (7.9-4b)$$

and the unavailability $Q_N(t)$ is seen to increase with time t . When $t \gg 1/\lambda$ (i.e. MTBF), equation (7.9-4b) is approximated as (Reference 5.24, p XI-11):

$$Q_N(t) \approx \lambda t \approx t/\text{MTBF}. \quad (7.9-5)$$

If subjected to periodic tests at T_T , the average unavailability of the non-repairable component is (Reference 5.24, p. XI-13):

$$Q_N(T_T) \approx (1/2) T_T/\text{MTBF}. \quad (7.9-6)$$

The MTTR, which stands for the Mean-Time-to-Repair (or Restore), is an often-used parameter to express the maintainability for a component or system. The MTTR is inserted for t in equation (7.9-2), along with MTBF, to predict the unavailability of a repairable component:

$$Q_R = 1 - \exp(-\text{MTTR}/\text{MTBF}). \quad (7.9-7)$$

Usually, $\text{MTTR} \ll \text{MTBF}$, so expression (7.9-7) is approximated as (Reference 5.24, p. XI-12):

$$Q_R \approx \text{MTTR}/\text{MTBF}$$

which is a common expression which succinctly illustrates that achieving high availability, i.e., achieving low unavailability, requires increasing MTBF and reducing MTTR.

The above expressions for unavailability are applicable to the time regime prior to when components reach wear-out; i.e., components are assumed to fail randomly in time per the exponential distribution. Such random failures are due to inherent, randomly occurring manufacturing flaws; or randomly occurring over-stress condition like voltage spikes). One aspect of a RAM program (or a reliability-centered-maintenance (RCM) program) is to assure that the conditions for random failure are maintained by operational controls, periodic inspection and/or refurbishment. Prediction for time of wear-out and refurbishment are part of the Predictive Maintenance process.

In this exponential model, MTBF is usually assumed to be constant in time but may be a function of environmental factors, where the baseline, or generic MTBF, is multiplied by one or more factors to account for the environment (e.g., effects not included in the basic value such as factors to represent radiation intensity, humidity, and/or temperature); see for example Reference 5.25, pg 341. The effect of accounting for the environment factors is to alter the inherent properties of a component so that it is less resistant to random variation in applied stresses, (e.g., to a slight over-voltage), or to trigger an incipient flaw.

In more detailed analyses, the MTBF can be modeled as dependent on both the environmental intensity and the exposure time in the hostile environment. For example, in some cases, it may be possible to take credit for annealing effects where environmental effects, (e.g., radiation damage), are reversed when the system is removed from the hostile environment.

In addition, components can be induced to fail by external influences such as collisions with other subsurface vehicles, irregularities in the electrical power system voltage or current, human actions, etc. A comprehensive analysis of the probability of occurrence of such causal factors is not part of the RAM program for the inspection system, *per se*, but is an appropriate activity for a general RAM program for the repository.

Designing for adequate reliability will involve provisions for redundancy in subsystems and/or hardening to withstand the environment where deemed necessary, depending on the criticality of a given operational or measurement function without interruption during the mission time. A highly critical function, for example, is the ability to move the inspection gantry in and out of the emplacement drift and back to the main drift without a breakdown of the motive or control systems because maintainability (corrective maintenance) is more difficult in the emplacement drift. By contrast, the failure of a thermal sensor during an inspection run might be deemed less critical. The design, therefore, might include redundancy in the motive and control systems, radiation shielding, use of radiation and heat-resistant component in motors and electrical conductors.

In addition, the possibility of failures induced by human error will be addressed for their effect on reliability and availability. Human factors engineering of the operational control system, preparation of clear procedures, and operator training will help to reduce the likelihood of such errors.

7.9.2 Maintainability Analysis and Design

In general, the design must include provisions for preventive and corrective maintenance. It appears that corrective maintenance of sensor subsystems on the inspection gantry can be performed in the main drifts or at maintenance facilities located at surface, away from the radiation and thermal hazards. Depending on cost and logistical constraints, the sensor subsystems might be designed for a remove-and-replace (R&R) maintenance philosophy. The design would accommodate ease of access and connectors and fasteners to facilitate R&R. Components so removed would be re-furnished for re-use or discarded.

In general, the maintainability provisions for the drive and control subsystems will assume preventive maintenance in accord with the reliability analysis. That is, periodic testing and refurbishment, using the principles of reliability-centered-maintenance (RCM) will be applied to assure a suitably low probability of failure during the mission time. Nevertheless, design must also include provision for rescue of a failed inspection gantry from an emplacement drift or turnout. How to accomplish this will be the subject for future analysis.

The primary constraints for maintainability for the inspection systems are the high radiation and temperature in the emplacement drifts and somewhat elevated temperatures in the turnouts which pose a high hazard to humans should there be a need to repair or rescue a gantry after a breakdown. In addition, space limitations in emplacement drift and turnouts will impede any maintenance operations (especially directly next to the gantry frame).

7.9.3 RAM Issues Related to the Remote Inspection System

Scheduled testing and preventative maintenance of the remote inspection system can be conducted periodically in human-rated areas in the perimeter main drifts and at maintenance areas located at the surface. However, during the time the remote inspection gantry is deployed inside an emplacement drift containing waste packages it will be inaccessible to personnel. It is very important that the remote inspection system work reliably. The consequences of a failed inspection gantry inside an emplacement drift can be significant. Conversely, the instrumentation used in the observation drifts, perimeter mains and exhaust main will be accessible to personnel for periodic testing, calibration, and repair or replacement and do not pose as significant RAM concerns. Therefore, this section provides an initial discussion focused on RAM issues related to the remote inspection system.

The principal subsystems of the mobile remote inspection system pose different RAM issues, depending on their function and criticality to mission success, as follows:

Locomotive Subsystem - Loss of function to move gantry on track while in emplacement drift is a critical issue. Failure of motors, gears, bearings, wheels, etc., could halt the operation. The critical issue for corrective maintenance is the ability to retrieve the gantry from an emplacement drift to permit hands-on repair. This might require use of a special retrieval gantry or other technique (e.g., cooling down the drift and bringing an emplacement gantry back in to retrieve the inspection gantry). Recovery from gantry derailment is a related but separate issue from RAM considerations for reliability and maintainability of the active locomotive subsystems. Reliability issues include environmentally enhanced failure rates for electrical insulation, motor windings, bearings and lubricants, etc. RCM should be applied to determine the optimal test and/or refurbishment program for the control system.

Control System - The criticality for loss of function for control of locomotive systems is essentially the same as for the locomotive system itself plus the additional concern that some failure modes might lead to a "runaway" gantry, driving into the drift at maximum speed until it hits mechanical stops installed on the track. There would appear to be less criticality for failure of the sensor control subsystem for one or more of the sensor subsystems since the gantry should be able to be driven back out of a drift to permit repair. A possible failure of the control of the remote manipulator arms could cause jamming or interference with the gantry movement and therefore will require special attention during the design process. It may be necessary to design remote manipulators with power-off fail-safe modes or breakaway actuators and mounts (see discussion under Remote Manipulation System in Section 7.6.5).

Prioritization of the RAM requirements for the sensor control subsystem (as for the sensors themselves) is an issue of the criticality of mission success for a given measurement. Reliability issues include environmentally induced failures of electronic and computer circuitry, spurious signals from ionizing radiation, insulation breakdown, etc. In addition, radiation hardening and shielding may be applied to reduce the environmental effects. RCM should be applied to determine the optimal test and/or refurbishment program for the control system.

Communication System - Failure of the communications system is similar to that of the control system. Portions of the communication system mounted on the gantry are subject to the same issues as described above for the control system, since such failures may result in loss of external control to drive the gantry back out of the drift. Radiation and thermal hardening and shielding are included in the design to improve reliability. As necessary, redundancy and diversity will be designed into key components and circuitry. Alternatively,

or in addition, the design can provide for easy removal and replacement (R&R) of failed modules to permit quick return to the mission.

Portions of the communication link mounted outside of the emplacement drift, however, will be subjected to a less hostile environment than the counterparts that enter the emplacement drifts. The duration and intensity of exposure, however, will be considered for reliability effects.

Sensor System - The criticality of failure of one or more of the sensor subsystems depends on the criticality or urgency of obtaining a given data point at any given time because repair (e.g., R&R) can be performed quite readily by driving the gantry back out of the emplacement drift to the main drift where hands-on maintenance can be performed. Prioritization of the RAM requirements for the sensor subsystem is then an issue of the criticality of mission success for a given measurement. Sensors critical to gantry operations will each have redundant backup sensors and systems that will eliminate the possibility of single point failures. Possible failures within the monitoring instrumentation packages and sensors, including the camera systems, thermal and radiation sensing instruments, etc., will not jeopardize recovery of the gantry from inside the emplacement drift, and therefore, will not require redundancy in design.

7.9.4 Recommendations for a Future RAM Program

A future RAM analysis program for the Performance Confirmation data acquisition system should support the selection among design alternatives and support optimization of design for cost versus success of the mission for the required maintainable service life of 125 years. The analysis should address issues such as:

- Random failure, inherent to particular sensors, mechanisms, etc.
- Environmental effects on failure rates
- Human exposure issues on maintenance activities; need for auxiliary shielding and/or cooling
- Applications of Preventive Maintenance (PM) and Reliability-Centered Maintenance (RCM) concepts
- Human Reliability Analysis (HRA) during operations and maintenance, installation, configuring for specific mission
- Maintenance Philosophy for various subsystems
- Repairability/Accessibility of various failure modes of each subsystem
- Logistic and Spare-parts support program

Reference 5.13 developed guidelines for establishing a RAM program for a prior concept for mined geologic disposal of high-level nuclear wastes. The guidebook provides instructions for applying both qualitative and quantitative methodology for RAM analysis and design support. Although Reference 5.13 was developed at a time when salt-dome sites were being considered, the techniques for defining, prioritizing, and analyzing RAM elements remain relevant. Techniques for simulation modeling are not included in Reference 5.13 as they had been exploited only in limited applications at the time.

As noted in Reference 5.13, "Application of many of the techniques ... can be quite time consuming and costly" and it asks "Should a comprehensive RAM analysis be applied to every component, equipment item or system?" The answer is "no", but efforts should be prioritized using a "decision tree" to suggest a level of RAM activity appropriate to a given unit: i.e, None; Minimum Effort; Moderate Effort; or Maximum Effort. The key elements in the decision process are "high confidence" in the performance based on prior knowledge or experience, "little effect or no effect on performance", "access for maintenance during operation", and degree of "uncertainty" about effect on performance or accessibility.

Depending on the level of RAM effort defined for a given unit, the program may apply one or more of the following:

- RAM Checklists (including Reliability Checklist; Maintainability Checklist)
- Failure Mode and Effects Analysis (FMEA) [or a variant such as Failure Modes, Effects and Criticality Analysis (FMECA)]
- Reliability Block Diagrams (RBD)
- Maintainability Evaluation (e.g., estimates of access times, repair times, radiation exposure of workers, etc.)
- Fault Tree Analysis (FTA); for detailed reliability analysis of subsystems and systems)
- Event Tree Analysis (ETA); to define RAM related scenarios

Except for the checklists which are qualitative, the other techniques can be applied both qualitatively and quantitatively. The qualitative application of FMEA, RBD, FTA, and ETA provide a structured technique to examine how and why a mission may fail or why a failure may be critical. The quantitative application of these techniques can help in optimization of cost vs performance.

If deemed appropriate, the operations of the inspection system can be modeled in a simulation.

To support a quantitative analysis, including simulation, the RAM program must also include a database development. Failure rate data for repository-specific components and equipment has to be developed. Where no experience data exists for the specific environment or duty, data synthesis and estimates must be developed. Environmental effects of radiation and temperature on failure rates must be included.

8. CONCLUSIONS

This analysis has met the objectives outlined in Section 1 by developing and describing five key preliminary designs for acquiring and processing repository performance confirmation data. The five primary systems related to data acquisition for PC were presented.

- 1) An initial design for exhaust air monitoring instrumentation and data acquisition within the ventilation system was developed and presented in Section 7.4
- 2) The feasibility of monitoring emplacement drifts using permanently installed in-situ instrumentation was evaluated and discussed in Section 7.5
- 3) An initial design for a remotely controlled inspection system that could be deployed for limited periods of time within the heated emplacement drifts was developed and presented in Section 7.6. This includes an initial thermal analysis to assess the length of time such a system might be able to withstand the nearly 200 °C environment.
- 4) An initial design for monitoring and gathering data from borehole instrumentation originating from within Observation Drifts or along perimeter drifts was developed and presented in Section 7.7.
- 5) An initial design concept for a subsurface data acquisition network was developed and discussed in Section 7.8

In addition to the initial design of these key systems, information was presented relating to the issues of equipment reliability, availability, and maintainability (RAM). Recommendations for a future RAM analysis and program are proposed.

This analysis has dealt with the issue of data collection, which, as can be seen, is an important portion of the large and complex performance confirmation program. Automating the data collection process of various parameters is feasible and viable.

The specific parameters which were addressed in the ventilation exhaust monitoring system (Section 7.4) were radiation, temperature and humidity. If additional parameters are required to be monitored, additional data acquisition input cards and possibly I/O racks could be added to accommodate them. The modular nature of data acquisition hardware is ideally suited for the PC program. Acquisition hardware can be located throughout the repository wherever inputs are required.

Section 7.5 of this analysis has addressed the possibility of locating data acquisition sensory equipment within the emplacement drifts. The extremely high temperature expected in the drifts tends to eliminate most types of instrumentation due to probable electrical component failure. Temperature sensors, such as thermocouples and RTD's, by their simplistic nature could survive for some time, but not 100 years. Further investigation of monitoring temperature within the emplacement drifts is required. Instrumentation to be abandoned in place would provide potentially valuable data for monitoring the very near-field (close-in) changes in the rock mass around the emplacement drifts.

From the initial thermal analysis presented in Section 7.6.6 it appears both possible and feasible to develop a remotely operated vehicle for temporary in-drift inspection tasks. The initial design of a "Remote Inspection Gantry", presented in Section 7.6.5, describes how vision systems, thermal monitoring instruments, radiological instruments, air and gas sensing instruments and remote manipulator systems could be used to acquire in-situ PC data from within closed, (i.e. heated), emplacement drifts. Mechanical layout and instrumentation and control diagrams are presented.

The key parameters for design as presented in Appendix D of the Performance Confirmation Concepts Study Report were reviewed in Section 7.7. A viable method to obtain many of the key parameters requiring continuous monitoring would be to construct observation drifts above the repository horizon from which boreholes could be drilled to approach the rock mass near the emplacement drifts. Selected instrumentation can be installed in the boreholes to obtain data in the altered zone. Data acquisition hardware could reside in the observation drift alcoves for transmission to surface facilities. Test alcoves from the main access drifts and from cross block ventilation drifts could also be used for instrumentation of the rock mass between the waste packages and the saturated zone.

A discussion of possible network topologies was presented in section 7.8. This network design requires additional effort but can be accomplished with a hybrid network of rings and buses. The fiber optic backbone could be routed around the perimeter of the repository with other ring networks down the exhaust main and up the South ramp. Buses or other ring networks could be routed from the exhaust main up to the observation drifts where connection to the data acquisition hardware can take place. The network can be designed with sufficient drop or access points to allow for the addition of data acquisition hardware and portable monitoring stations.

9. ATTACHMENTS

<u>Attachment</u>	<u>Description</u>	<u>Date</u>
I	ROM Estimate of Remote Inspection Gantry Mass and Power	2/26/97
II	Preliminary Thermal Analysis of Remote Inspection Gantry	3/18/97
III	Commercially Available Technologies	2/12/97
IV	Remote Inspection Gantry: Shielding Analysis Computer Runs	
	Case I	2/26/97
	Case II	2/26/97
	Case III	2/26/97
	Case IV	2/26/97
V	Thermal Analysis Input Files	3/18/97

ATTACHMENT I

ROM Estimate of Remote Inspection Gantry Mass and Power

This attachment contains initial rough order-of-magnitude (ROM) estimates and approximations of mass and power needs related to the Remote Inspection Gantry. This analysis is being performed early in the design development process and well in advance of subsystem design or component selection. The initial estimates and approximations contained in this Attachment are useful in the concept development process and in assessing the relative impact of various design issues and features on the overall design concept.

ROM Mass Estimate:

For concept evaluation purposes it will be helpful to develop an initial estimate of the overall mass of the proposed Remote Inspection Gantry concept. This ROM estimate will provide an early indication that basic design parameters can be developed that are consistent with a viable design concept. The ROM mass estimate will also be used later in the Attachment to obtain ROM estimates of power and thermal control needs. These values are presented only as a starting place for evaluation and will undergo many significant changes as the design evolves. In this initial estimate, no effort was made to minimize or optimize the mass value.

Preliminary estimates for radiation shielding were discussed in Section 7.6.7. If a decision is made to use commercial-grade electronics that are sensitive to radiation, it is possible that some components may need substantial amounts of shielding in the form of steel plates 102 mm thick. Using this type of steel shielding has a significant impact on the overall ROM mass estimate and therefore two cases are considered: a) a Remote Inspection Gantry with little or no shielding, i.e. the "minimal shielding" case, and b) a gantry with enough shielding material to fully protect sensitive commercial grade electronics from the effects of the radiation levels expected, (i.e. the "maximum shielding" case).

Only one side of the steel electronics enclosure (i.e. the side nearest the waste package) needs to be 102 mm thick. The other 5 sides of the box can be substantially thinner because they will only need to provide protection from back scatter and reflected radiation. The side of the enclosure nearest the waste package will be sufficiently large in relation to the electronics so as to provide a shadow shield that protects the electronics from direct line-of-sight exposure to the waste package.

Table I-1
Remote Inspection Gantry ROM Mass Estimate

Remote Inspection Gantry Subsystem	Basis of Estimate Notes and Comments	Inspection Gantry w/ Min Shielding	Inspection Gantry w/ Max Shielding
Steel Structural Frame	Composed of 60 m of 100 x 100 mm tube steel with a 7 mm wall thickness, (Approx density of steel 7.8 g/cm ³ , Section 4.3.2.11)	1200 kg (2,646 lbs)	1200 kg (2,646 lbs)
Steel Radiation Shielding	<ul style="list-style-type: none">• (2) steel electronics boxes, 0.5 x 0.5 x 0.3 m, with 102 mm front, 50 mm sides and back ($\approx$ 800 kg)• shielding of instruments ($\approx$ 1200 kg)• min shielding (instrumentation and electronics enclosures, heat sinks, etc.) approximately $\approx$ 200 kg	200 kg (441 lbs)	2000 kg (4,410 lbs)
Locomotive Drive System	Mass estimate for motors, drives, wheel blocks, and mounting structures	500 kg (1,103 lbs)	500 kg (1,103 lbs)
Miscellaneous	A lump-sum estimate of Electronics, Instrumentation, Actuators, Cooling, etc.	1000 kg (2205 lbs)	1000 kg (2205 lbs)
	Remote Inspection Gantry ROM Mass Estimate:	2900 kg (6395 lbs)	4700 kg (10,364 lbs)

Inspection Scenarios:

The concept of operations is described in Section 7.6.3. It is evident that there may be several different inspection task scenarios that will be desired of Remote Inspection Gantry. Each task will require different in-drift resident times, different speed and acceleration profiles, and a different number and duration of stops (see Figure I-1, below).

As a starting point, it will be helpful to consider two widely different scenarios. "Scenario A" depicts a slow speed, non-stop, full drift survey. In addition to utilizing the camera system during the entire survey, other selected instruments, such as the thermal monitoring instruments may also be powered up. When the Remote Inspection Gantry arrives at the end of the drift, it will decelerate to a stop and then accelerate back the opposite direction toward the emplacement drift entrance. During the return travel monitoring instruments may be turned off.

Another scenario, "Scenario B", has the Remote Inspection Gantry making several inspection stops. For the purpose of developing initial ROM estimates of power and in-drift resident-times the number and duration of inspection stops can be assumed to be 4 stops, with minor repositioning at each inspection stop.

Figure I-1 Remote Inspection Gantry Task Scenarios

ROM Estimate of In-drift Resident Time:

In order to facilitate the estimating process, initial ROM approximations of maximum vehicle operating speed, acceleration, and deceleration are assumed. For reasons relating to equipment safety, reliability, and power consumption, the maximum (top speed) of the inspection gantry should be limited to fairly slow speeds. For this initial estimate, the top speed of the inspection gantry can be assumed to be approximately 10 km/hr (or 2.78 m/s) (Section 4.3.2.10). Fast accelerations are not particularly desirable. It will be adequate if the inspection gantry could attain top speeds from a standing stop in approximately 20 seconds. This would result in an acceleration of approximately 0.139 m/s^2 [acceleration = (final velocity - initial velocity)/ time]. There may be a need for a fairly quick stopping capability. Stopping the vehicle from full speed to a complete stop in 4 seconds would result in deceleration rates of approximately 0.695 m/s^2 .

If the longer emplacement drifts are approximately 600 m in length (from the entrance of the drift to where it intersects with the exhaust drift raise) (Section 4.3.2.1), the total round trip distance for a full drift survey will be approximately 1200 m. Traveling at a speed of 10 km/hr the Remote Inspection Gantry could traverse the round-trip non-stop emplacement drift distance in approximately 7.2 minutes [travel time = (distance/rate)]. Allowing time for acceleration, deceleration, stopping and reversing direction, an initial ROM estimate of travel time could be roughly 10 minutes. This does not include the time required to load and unload the inspection gantry into the heated emplacement drift.

In evaluating Scenario B above it can be assumed that the task includes inspection of the waste package furthest from the emplacement drift entrance and that the 4 inspection stops average approximately 15 minutes in duration each including the time required for deceleration, repositioning and accelerating to the next inspection location. In this scenario the ROM estimate of in-drift resident time would be approximately 70 minutes.

ROM Estimate of Drive Power

For estimation purposes, it can be assumed that the rolling resistance for the vehicle can be assumed to be quite low. Typical coefficients for rolling resistance for steel wheels on a dry steel rail is approximately 0.25 mm (0.01 in) (Reference 5.27, pg 334 of Beers). The calculation to determine the force required to keep a rolling vehicle rolling at a constant speed on a level surface is as follows:

$$F_r = W \cdot b/r$$

Where, F_r = the force that should be applied to keep the wheel rolling at constant speed,
 W = the load supported by the wheel,
 b = coefficient for rolling resistance of steel wheels on dry steel rail
 r = the radius of the wheel

Assuming the wheels are 250 mm in diameter (125 mm in radius) and the weight of the vehicle is 46 kN (kilo-Newtons) [$W = \text{mass} \times \text{acceleration of gravity, i.e., } 4700 \text{ kg} \times 9.80 \text{ m/s}^2$]. If the weight is evenly distributed over the 4 drive wheels (i.e. $46 \text{ kN} / 4 \text{ wheels} = 11.5 \text{ kN/wheel}$), where 1 kN equals 1000 N, an estimate of the force per wheel required to keep the vehicle rolling at a constant speed would be:

$$F_r = (11,500 \text{ N} \cdot 0.00025 \text{ m}) / 0.125 \text{ m} = 23 \text{ N}$$

This indicates that a relatively small force (and energy) will be needed to keep the inspection gantry rolling at constant speeds. Note, this initial estimate neglects the effects of the slight grade (slope) being considered for the emplacement drift.

The power required to keep the inspection gantry rolling at a constant speed can be approximated by the following equation (Reference 5.39):

$$P = F \cdot V$$

Where, P = Power in watts
 F = Force in Newtons
 V = Velocity in meters/second

Using the above estimates for F_r (multiplied times 4 because there are 4 drive wheels) and the velocity 2.78 m/s, results in an initial ROM estimate of the power required to keep the gantry rolling at a constant speed, which is:

$$P = (23 \text{ N}) \cdot (4) \cdot (2.78) = 256 \text{ watts}$$

(Or, 0.34 hp (horsepower), since 1 hp = 746 watts)

The major power draw however will not come from keeping the Remote Inspection Gantry rolling, it will be during times of acceleration. A ROM estimate of the power needs during acceleration can be approximated by utilizing Newton's Law of Motion (which states that Force = mass · acceleration). For the ROM it can be assumed that the inspection gantry operates on a flat surface, that friction levels are negligible, the mass of the vehicle will be 4700 kg, and the acceleration will be 0.139 m/s^2 .

$$F_{va} = m \cdot a$$

Where, F_{va} = the force due to vehicle acceleration
 m = mass of the vehicle
 a = acceleration of the vehicle
 N = Newtons ($1 N = 1 \text{ kg} \cdot \text{m/s}^2$)

$$\begin{aligned} F_{va} &= (4700 \text{ kg}) \cdot (0.139 \text{ m/s}^2) \\ &= 653 \text{ N} \end{aligned}$$

For the purpose of this ROM estimate, the frictional losses and inefficiencies in the motors, gears, and wheels, and the effect of a slight slope or grade, can be compensated for by assuming a 60% efficiency for the drive locomotive input force (The efficiency, n , can be represented by the output drive force divided by the input drive force. This can be expressed as: $n = F_{va} / F'_{va}$. Therefore F'_{va} is equal to $653 \text{ N} / 0.6$, and F'_{va} , compensated for frictional losses and inefficiencies becomes 1088 N). To obtain an initial ROM estimate of the peak power needed to accelerate the inspection gantry from a complete stop to its top speed of 10 km/hr , the power equation cited above can be used with the velocity assumed to be 2.78 m/s :

$$\begin{aligned} P &= F \cdot V \\ P &= (1088 \text{ N}) \cdot (2.78 \text{ m/s}) = 3,025 \text{ watts} \end{aligned}$$

Note that according to the acceleration profile identified above, the inspection gantry would need peak power for 20 seconds, or less, to accelerate to the maximum operating speed of 2.78 m/s .

ROM Estimate of Remote Inspection Gantry Power Needs:

As indicated previously, at this stage of the design process, subsystems have not yet been designed, nor have the components selected, therefore, only an initial ROM estimate of design features and issues can be made at this time. However, it will be useful to obtain an initial estimate of how much power might be needed to operate a system like the Remote Inspection Gantry.

Since electrical systems and components have not yet been selected, the power requirements for the electronic systems, such as the cameras and PLCs, can be approximated by examining conventional, commercially available, equivalent systems (i.e. equivalent in sophistication and function) (see Attachment III and References 5.7 and 5.8).

An initial ROM assessment of the power needs on-board the Remote Inspection Gantry is shown in Table I-3. At this point in the estimating process, no attempt has yet been made to minimize or optimize the amount of power needed by the system.

Figure II-2 Finite Element Model of Emplacement Drift, Waste Package & Electronics Box
CASE 1: Without Insulation, Internal Heat and Active Cooling

Figure II-3 Finite Element Model of the Electronics Box.
Results Shown After $\approx$ 30 Minutes of Heating Within Emplacement Drift
CASE 1: Without Insulation, Internal Heat and Active Cooling

Legend

3D = three dimensional
DD = drift diameter
DWP = diameter of WP
LWP = length of WP
Dist. = distance between WP and box

Note: the plotted data points for some temperatures may be coincident

Figure II-4 Temperatures Inside the Electronics Box vs. Time
CASE 2: With 10 mm of insulation; without internal heat and cooling

Figure II-5 Finite Element Model of Emplacement Drift, Waste Package, Electronics Box and Insulation Box
CASE 2: With 10 mm of insulation; without internal heat and cooling

Figure II-6 Finite Element Model of the Electronics Box.
Results Shown After $\approx$ 73 Minutes of Heating Within Emplacement Drift
CASE 2: With 10 mm of insulation; without internal heat and cooling

Figure II-7 Finite Element Model of the Insulation Box
Results Shown After $\approx$ 73 Minutes of Heating Within Emplacement Drift
CASE 2: With 10 mm of insulation; without internal heat and cooling

Figure II-8 Temperatures Inside the Electronics Box vs. Time
CASE 3: With 50 mm of insulation; without internal heat and cooling

Figure II-9 Finite Element Model of Emplacement Drift, Waste Package, Electronics Box and Insulation Box
CASE 3: With 50 mm of insulation; without internal heat and cooling

Figure II-10 Finite Element Model of the Electronics Box.
Results Shown After $\approx$ 226 Minutes of Heating Within Emplacement Drift
CASE 3: With 50 mm of insulation; without internal heat and cooling

Figure II-11 Finite Element Model of the Insulation Box
Results Shown After $\approx$ 226 Minutes of Heating Within Emplacement Drift
CASE 3: With 50 mm of insulation; without internal heat and cooling

Legend

3D = three dimensional
DD = drift diameter
DWP = diameter of WP
LWP = length of WP
Dist. = distance between WP and box

Note: the plotted data points for some temperatures may be coincident

Figure II-12 Temperatures Inside the Electronics Box vs. Time
CASE 4: With 10 mm of insulation, 100 watts of internal heat, without cooling

Figure II-13 Finite Element Model of Emplacement Drift, Waste Package, Electronics Box and Insulation Box
CASE 4: With 10 mm of insulation, 100 watts of internal heat, without cooling

Figure II-14 Finite Element Model of the Electronics Box.
Results Shown After $\approx$ 70 Minutes of Heating Within Emplacement Drift
CASE 4: With 10 mm of insulation, 100 watts of internal heat, without cooling

Figure II-15 Finite Element Model of the Insulation Box
Results Shown After $\approx$ 70 Minutes of Heating Within Emplacement Drift
CASE 4: With 10 mm of insulation, 100 watts of internal heat, without cooling

Legend

3D = three dimensional
DD = drift diameter
DWP = diameter of WP
LWP = length of WP
Dist. = distance between WP and box

Note: the plotted data points for some temperatures may be coincident

Figure II-16 Temperatures Inside the Electronics Box vs. Time
CASE 5: With 10 mm of insulation, and 400 watts of internal heat, without cooling

Figure II-17 Finite Element Model of Emplacement Drift, Waste Package, Electronics Box and Insulation Box
CASE 5: With 10 mm of insulation, and 400 watts of internal heat, without cooling

Figure II-18 Finite Element Model of the Electronics Box.
Results Shown After $\approx$ 60 Minutes of Heating Within Emplacement Drift
CASE 5: With 10 mm of insulation, and 400 watts of internal heat, without cooling

Figure II-19 Finite Element Model of the Insulation Box
Results Shown After $\approx$ 60 Minutes of Heating Within Emplacement Drift
CASE 5: With 10 mm of insulation, and 400 watts of internal heat, without cooling

Legend	
3D	= three dimensional
DD	= drift diameter
DWP	= diameter of WP
LWP	= length of WP
Dist.	= distance between WP and box
Note: the plotted data points for some temperatures may be coincident	

Figure II-20 Temperatures Inside the Electronics Box vs. Time

CASE 6: With 10 mm of insulation, 400 watts of internal heat inside the device box and active fluid cooling at 0°C between the device and insulating boxes, with the Convective Heat Transfer Coefficient = 4.5 W/m²·K

Figure II-21 Finite Element Model of Emplacement Drift, Waste Package, Electronics Box and Insulation Box

CASE 6: With 10 mm of insulation, 400 watts of internal heat inside the device box and active fluid cooling at 0°C between the device and insulating boxes, with the Convective Heat Transfer Coefficient = 4.5 W/m²·K

Figure II-22 Finite Element Model of the Electronics Box.

Results Shown After $\approx$ 195 Minutes of Heating Within Emplacement Drift

CASE 6: With 10 mm of insulation, 400 watts of internal heat inside the device box and active fluid cooling at 0°C between the device and insulating boxes, with the Convective Heat Transfer Coefficient = $4.5 \text{ W/m}^2\cdot\text{K}$

Figure II-23 Finite Element Model of the Insulation Box

Results Shown After $\approx$ 195 Minutes of Heating Within Emplacement Drift

CASE 6: With 10 mm of insulation, 400 watts of internal heat inside the device box and active fluid cooling at 0°C between the device and insulating boxes, with the Convective Heat Transfer Coefficient = $4.5 \text{ W/m}^2\cdot\text{K}$

Legend	
3D	= three dimensional
DD	= drift diameter
DWP	= diameter of WP
LWP	= length of WP
Dist.	= distance between WP and box
Note: the plotted data points for some temperatures may be coincident	

Figure II-24 Temperatures Inside the Electronics Box vs. Time
CASE 7: With 10 mm of insulation, 400 watts of internal heat inside the device box and active fluid cooling at 0°C between the device and insulating boxes, with the Convective Heat Transfer Coefficient = 12 W/m²·K

Figure II-25 Finite Element Model of Emplacement Drift, Waste Package, Electronics Box and Insulation Box

CASE 7: With 10 mm of insulation, 400 watts of internal heat inside the device box and active fluid cooling at 0°C between the device and insulating boxes, with the Convective Heat Transfer Coefficient = 12 W/m²-K

Figure II-26 Finite Element Model of the Electronics Box.
Results Shown After ≈ 720 Minutes of Heating Within Emplacement Drift
CASE 7: With 10 mm of insulation, 400 watts of internal heat inside the device box and active fluid cooling at 0°C between the device and insulating boxes, with the Convective Heat Transfer Coefficient = $12 \text{ W/m}^2\cdot\text{K}$

Figure II-27 Finite Element Model of the Insulation Box
Results Shown After ≈ 720 Minutes of Heating Within Emplacement Drift
CASE 7: With 10 mm of insulation, 400 watts of internal heat inside the device box and active fluid cooling at 0°C between the device and insulating boxes, with the Convective Heat Transfer Coefficient = $12 \text{ W/m}^2\cdot\text{K}$

ATTACHMENT III

Date Created: 2/12/97

Commercially Available Technologies

This attachment contains commercial vendor related information and specification sheets for technologies discussed within this analysis.

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SPECIAL INSTRUCTION SHEET

1. QA: QA

Page: 1 of: 1

Complete Only Applicable Items

This is a placeholder page for records that cannot be scanned.

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Addendum 1

EQUIPMENT CORP; INDUSTRIAL COMPUTER SOURCE; ALLEN-BRADLEY

ATTACHMENT IV

REMOTE INSPECTION GANTRY: SHIELDING ANALYSIS COMPUTER RUNS

This attachment describes the MCNP4A computer runs for both unshielded and shielded remote inspection gantry (Section 6.2). See related design input parameters and assumptions in Sections 4.1 and 4.3.4. The runs include the following cases:

- Case I: Unshielded gamma dose rates for an intact waste package (WP)
- Case II: Unshielded neutron dose rates for an intact waste package
- Case III: Unshielded gamma dose rates for a breached waste package
- Case IV: Shielded gamma dose rates for an intact waste package

The unshielded neutron dose rates were calculated for the intact waste package only. Since comparison of Cases I and II shows that the neutron results are negligible as compared with the gamma results, there is no need for additional neutron calculations. The pertinent information related to the MCNP4A runs is listed below:

<u>Case</u>	<u>Input File</u>	<u>Output File</u>	<u>Run Date</u>
I	infwplga	infwplga.out	02/01/97
II	infwplna	infwplna.out	02/07/97
III	infwplgb	infwplgb.out	02/01/97
IV	infwplgc	infwplgc.out	02/01/97

The radiation source spectrum is normalized to 1.0 for input to the MCNP4A code. The following table shows an example of the normalized neutron source energy spectrum:

<u>Energy (MeV)</u>	<u>Unnormalized Spectrum*</u>	<u>Normalized Spectrum*</u>
6.43-20.0	2.345E+5	0.0183
3.00-6.43	2.691E+6	0.2099
1.85-3.00	3.002E+6	0.2341
1.40-1.85	1.680E+6	0.1310
0.90-1.40	2.265E+6	0.1767
0.40-0.90	2.466E+6	0.1924
0.10-0.40	4.827E+5	0.0376
0.00-0.10	0.0	0.0
Total	1.282E+7	1.0

*Note: In the table above, the unnormalized spectrum taken directly from Reference 5.31 (Section

4.1.1), which is converted to a normalized spectrum for computer input . Example conversion: for the 6.43 - 20.0 MeV neutrons, the normalized spectrum = $2.345E+5/1.282E+7 = 0.0183$.

For the intact waste package, all the results for both unshielded and shielded cases are normalized to a radiation field of 100 rad/hr at the waste package surface, consistent with assumption Section 4.3.4.4. Figure IV-1 depicts the geometric model for the intact waste package unshielded case. The dry tuff medium is used for the emplacement drift wall. Presence of water in the tuff medium affects mainly neutron results, which are negligible relative to gamma results. The hydrogen content in water tends to reduce neutron dose albedo for back-scattering from the drift wall, because of a large neutron energy loss per collision in hydrogen. In other words, use of dry tuff is conservative for neutron dose.

The analysis demonstrates that the assumption of 100 rad/hr is conservative, as compared with the unnormalized results which represent the expected radiation conditions for design basis fuel. Table IV-1 summarizes the MCNP4A results for the unshielded case at the waste package surface, and 280 mm and 760 mm from the waste package surface. The shielded case with a steel thickness of 102 mm is presented in Table IV-2. The model for the shielded case is constructed by adding 102 mm of steel for the electronic box to the model for the unshielded case.

In a worst-case scenario where both the inner and outer waste packages have been breached (an extremely unlikely situation), the radiation field near the breach could be much higher than the 100 Rem/hr or 100 rad/hr for an intact waste package. Preliminary estimates with the qualified MCNP4A code (Reference 5.32) show that the breached waste package with loss or rupture of the inner and outer barriers would result in a maximum radiation level on the order of about 10,000 rad/hr at the location of the electronic box. This radiation level is based on the condition of the breached waste package for which the inner and outer barriers have been removed, and the source radioactivity in spent fuel assemblies has not been redistributed. Attachment IV provides listing of the computer input and output files for determination of the radiation environment with the MCNP4A code. In this scenario, radiation sensors on the Remote Inspection Gantry would provide adequate advanced warning of increased radiation levels to the operator and the gantry could be kept at safe distances from the incident.

RADIAL DIMENSIONS ARE
SHOWN IN CENTIMETERS

FIGURE IV-1
GEOMETRIC MODEL FOR INTACT
WASTE PACKAGE

TABLE IV-1
RADIATION DOSE RATES FOR THE UNSHIELDED CASE

Distance from WP Surface (mm)	Unnormalized Dose Rate [rad(Si)/hr]			Normalized ^a Result
	Gamma	Neutron	Total	[rad(Si)/hr]
Intact WP ^c				
0	26.9	0.005	26.9	100
280 ^b	16.7	nil	16.7	62
760 ^b	12.8	nil	12.8	48
Breached WP ^d				
0	16,000	nil	16,000	n/a
280 ^b	10,100	nil	10,100	n/a
760 ^b	7,800	nil	7,800	n/a

Notes:

- a Normalized to 100 rad/hr at the waste package surface for the intact waste package.
- b Approximate locations of the electronic box measured from the maximum WP outer diameter (see Fig. IV-1).
- c Output file: infwp1ga.out for gammas and infwp1na for neutrons
- d Output file: infwp1gb.out

TABLE IV-2
RADIATION DOSE RATES FOR THE SHIELDED CASE

Distance from WP Surface (mm)	Unnormalized Dose Rate [rad(Si)/hr]			Normalized ^a Result
	Gamma	Neutron	Total	[rad(Si)/hr]
Intact WP ^d				
0	27.2	.005	27.2 ^c	100
280	16.7	nil	16.7	61
382 ^b	0.264	nil	0.544	≈ 1

Notes:

- a Normalized to 100 rad/hr at the waste package surface.
- b With 102 mm (4 in.) of steel between the waste package and electronic box.
- c Slight difference from Table IV-1, due to statistics in results.
- d Output file: infwp1gc.out for gammas

IV.1 INPUT AND OUTPUT FILES FOR CASE I (Gamma, Unshielded, Intact WP)

```
lmcnp version 4a ld=10/01/93 02/01/97 08:48:55
inp=infwp1ga probid = 02/01/97 08:48:55

1- MGDS waste package and drift wall primary gamma analysis
2- c primary gammas from 21 FWR fuel assemblies in waste package
3- c 48086 MWD/MTU, 4.2% initial enrichment and 10 years old
4- c infinite axial height model
5- c maximum waste package od=2.0 m
6- c drift inside diameter=5.1 m
7- c evaluation of radiation environment for electronic box
8- c intact waste package
9- c
10- c fuel region (homogenized, divided in 5 cells for source biasing)
11- 101 1 -3.0431 -101 12 -13
12- 102 1 -3.0431 101 -102 12 -13
13- 103 1 -3.0431 102 -103 12 -13
14- 104 1 -3.0431 103 -104 12 -13
15- 105 1 -3.0431 104 -105 12 -13
16- c liner for fuel basket on the outside
17- 1 4 -8.0038 105 -1 12 -13
18- c WP radial gap
19- 111 5 -0.001225 1 -111 12 -13
20- c WP inner barrier (2 cm)
21- 2 2 -8.14 111 -2 12 -13
22- c WP outer barriers (10 cm total)
23- 3 3 -7.832 2 -3 12 -13
24- 4 3 -7.832 3 -4 12 -13
25- c air space between waste package and drift
26- 8 5 -0.001225 4 -8 12 -13
27- 81 5 -0.001225 8 -81 12 -13
28- 82 5 -0.001225 81 -82 12 -13
29- 9 5 -0.001225 82 -9 12 -13
30- c drift wall (-30 cm modeled)
31- 10 6 -2.22 9 -10 12 -13
32- 11 6 -2.22 10 -11 12 -13
33- c zero importance cell
34- 12 0 11:-12:13
35-
36- 101 cz 20.0
37- 102 cz 35.0
38- 103 cz 45.0
39- 104 cz 54.0
40- 105 cz 61.0
41- 1 cz 62.68
42- 111 cz 69.45
43- 2 cz 71.45
44- 3 cz 76.45
45- 4 cz 81.45
46- 8 cz 128.0 $-11 in. from max. WP envelope
47- 81 cz 176.0 $-30 in. from max. WP envelope
48- 82 cz 245.0
49- 9 cz 255.0
50- 10 cz 270.0
51- 11 cz 285.0
52- *12 pz 0.0
53- *13 pz 10.0
54-
55- c active fuel region (smear density 3.0431 g/cc)
56- m1 7014 -0.00005
57- 8016 -0.10540
58- 24000 -0.00017
59- 26000 -0.00035
60- 40000 -0.17140
61- 50000 -0.00244
62- 92235 -0.00523
63- 92236 -0.00419
64- 92238 -0.70508
65- 94239 -0.00359
66- 94240 -0.00129
67- 94241 -0.00082
68- c alloy 825 (8.14 g/cc)
69- m2 6000 -0.0005
70- 13027 -0.0020
71- 14000 -0.0050
72- 16032 -0.0003
73- 22000 -0.0090
74- 24000 -0.2150
75- 25055 -0.0100
76- 26000 -0.2857
77- 28000 -0.4200
78- 29000 -0.0225
79- 42000 -0.0300
80- c A516 carbon steel (7.832 g/cc)
81- m3 6000 -0.0022
82- 14000 -0.00275
83- 15031 -0.00035
84- 16032 -0.00035
85- 25055 -0.0090
86- 26000 -0.98535
87- c liner [SS316B6A (vf=0.3448)+A825 (vf=0.6552), 8.0038 g/cc]
```

```

88-      m4      5010  -0.00077
89-      5011  -0.00351
90-      6000  -0.00043
91-      7014  -0.00033
92-      13027 -0.00133
93-      14000 -0.00584
94-      15031  -0.00015
95-      16032  -0.00030
96-      22000  -0.00600
97-      24000  -0.20686
98-      25055  -0.01336
99-      26000  -0.39270
100-     28000  -0.32505
101-     29000  -0.01499
102-     42000  -0.02836
103-      c      air (0.001225 g/cc)
104-     m5      7014  -0.8
105-     8016  -0.2
106-      c      dry tuff material (2.22 g/cc)
107-     m6      8016  -0.49863
108-     11023 -0.02909
109-     12000  -0.00077
110-     13027  -0.06513
111-     14000  -0.36898
112-     15031  -0.00004
113-     19000  -0.02641
114-     20000  -0.00322
115-     22000  -0.00056
116-     25055  -0.00035
117-     26000  -0.00682
118-      c      Si element for tally use
119-     m7      14000  1.0
warning. material 7 is used only for tallying.
120-      mode    p
121-     isp:p    0.25 0.35 0.5 0.7 1 1 1 2 4 15 4r 15 4 0
122-     esplt:p  0.5 0.25 0.5 0.1
123-     phys:p   3.0
124-     sdef     cel=d1 pos=0 0 5.0 rad=fcel d4 ext=d2 erg=d3 axs=0 0 1
125-     sil      1 101 102 103 104 105
126-     spl      0.1075 0.2217 0.2150 0.2395 0.2164
127-     sbl      0.5 1.0 1.5 2.0 3.0
128-     sil2     5.0
129-     sil3     0.45 0.70 1.0 1.5 2.0
130-     sp3      0.0 0.8484 0.0826 0.0681 0.0009
131-     sb3      0.0 0.2 0.1 0.6 0.1
132-     ds4      s 5 6 7 8 9
133-     sil5     0.0 20.0
134-     sil6     20.0 35.0
135-     sil7     35.0 45.0
136-     sil8     45.0 54.0
137-     sil9     54.0 61.0
138-     fc42     surface gamma dose rates---rad(Si)/hr
139-     e42      0.045 0.1 0.45 0.70 1.0 1.5 2.0 3.0
140-     f42:p    4 8 81 82 9
141-      c      multiplier=(5.51+16 photons/s for 0.45 - 2.0 MeV)(10/360.18 for 10 cm)
142-      c      (1/28.0855*0.6023 for 1 g Si)(1.602-6 ergs/MeV)(3600 sec/hr)
143-      c      /(100 ergs/g per rad)=1.892+9
144-      c      7=material no. 7 for silicon
145-      c      -5=total photon cross section position
146-      c      -6=heating number position
147-     fm42     1.892+9 7 -5 -6
148-     fq0      e f
149-     ctme     100.0
150-     nps      6000000

```

warning. 2 of the materials had unnormalized fractions.
lcells

print table 60

cell	mat	atom density	gram density	volume	mass	photon pieces importance	
1	101	1	2.11253E-02	3.04310E+00	1.25664E+04	3.82407E+04	1 2.5000E-01
2	102	1	2.11253E-02	3.04310E+00	2.59181E+04	7.88715E+04	1 3.5000E-01
3	103	1	2.11253E-02	3.04310E+00	2.51327E+04	7.64814E+04	1 5.0000E-01
4	104	1	2.11253E-02	3.04310E+00	2.79916E+04	8.51812E+04	1 7.0000E-01
5	105	1	2.11253E-02	3.04310E+00	2.52898E+04	7.69595E+04	1 1.0000E+00
6	1	4	8.76062E-02	8.00380E+00	6.52768E+03	5.22462E+04	1 1.0000E+00
7	111	5	5.13692E-05	1.22500E-03	2.81022E+04	3.44252E+01	1 1.0000E+00
8	2	2	8.69963E-02	8.14000E+00	8.85301E+03	7.20635E+04	1 2.0000E+00
9	3	3	8.54217E-02	7.83200E+00	2.32321E+04	1.81954E+05	1 4.0000E+00
10	4	3	8.54217E-02	7.83200E+00	2.48029E+04	1.94256E+05	1 1.5000E+01
11	8	5	5.13692E-05	1.22500E-03	3.06302E+05	3.75220E+02	1 1.5000E+01
12	81	5	5.13692E-05	1.22500E-03	4.58421E+05	5.61566E+02	1 1.5000E+01
13	82	5	5.13692E-05	1.22500E-03	9.12601E+05	1.11794E+03	1 1.5000E+01
14	9	5	5.13692E-05	1.22500E-03	1.57080E+05	1.92423E+02	1 1.5000E+01
15	10	6	6.54011E-02	2.22000E+00	2.47400E+05	5.49229E+05	1 1.5000E+01
16	11	6	6.54011E-02	2.22000E+00	2.61538E+05	5.80611E+05	1 4.0000E+00
17	12	0	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0 0.0000E+00
total				2.55176E+06 1.98838E+06			
minimum source weight = 5.1931E-03				maximum source weight = 7.5229E+00			

2 warning messages so far.
lcross-section tables

print table 100

Title: Performance Confirmation
Data Acquisition System

DI: BCAI00000-01717-0200-00002 REV 00
ATTACHMENT IV Date: 2/26/97 Page: IV-7 of IV-26

table	length	
tables from file mcplib2		
5000.01p	389	12/13/82
6000.01p	389	12/13/82
7000.01p	389	12/13/82
8000.01p	389	12/13/82
11000.01p	401	12/13/82
12000.01p	409	12/13/82
13000.01p	409	12/13/82
14000.01p	409	12/13/82
15000.01p	409	12/13/82
16000.01p	409	12/13/82
19000.01p	409	12/13/82
20000.01p	417	12/13/82
22000.01p	417	12/13/82
24000.01p	417	12/13/82
25000.01p	417	12/13/82
26000.01p	417	12/13/82
28000.01p	429	12/13/82
29000.01p	429	12/13/82
40000.01p	461	12/13/82
42000.01p	461	12/13/82
50000.01p	461	12/13/82
92000.01p	533	12/13/82
94000.01p	533	12/13/82
total	9803	
maximum photon energy set to 100.0 mev (maximum electron energy)		
tables from file el2		
5000.01e	478	11/16/88
6000.01e	478	11/16/88
7000.01e	478	11/16/88
8000.01e	478	11/16/88
11000.01e	478	11/16/88
12000.01e	478	11/16/88
13000.01e	478	11/16/88
14000.01e	478	11/16/88
15000.01e	478	11/16/88
16000.01e	478	11/16/88
19000.01e	478	11/16/88
20000.01e	478	11/16/88
22000.01e	478	11/16/88
24000.01e	478	11/16/88
25000.01e	478	11/16/88
26000.01e	478	11/16/88
28000.01e	478	11/16/88
29000.01e	478	11/16/88
40000.01e	478	11/16/88
42000.01e	478	11/16/88
50000.01e	478	11/16/88
92000.01e	478	11/16/88
94000.01e	478	11/16/88
1decimal words of dynamically allocated storage		
general	417604	
tallies	7056	
bank	6403	
cross sections	9803	
total	439638	
.....		
dump no.	1 on file runtpe	nps = 0 coll = 0 ctm = 0.00 nrm = 0
2 warning messages so far.		
.....		
dump no.	2 on file runtpe	nps = 408462 coll = 2066260 ctm = 15.00 nrm = 23402111
.....		
dump no.	3 on file runtpe	nps = 816018 coll = 4129645 ctm = 30.01 nrm = 46774936
.....		
dump no.	4 on file runtpe	nps = 1224154 coll = 6195814 ctm = 45.01 nrm = 70164331
.....		
dump no.	5 on file runtpe	nps = 1632489 coll = 8262331 ctm = 60.02 nrm = 93570629
.....		
dump no.	6 on file runtpe	nps = 2040045 coll = 10328646 ctm = 75.02 nrm = 116972607
.....		
dump no.	7 on file runtpe	nps = 2448308 coll = 12393874 ctm = 90.03 nrm = 140372059

Title: Performance Confirmation
Data Acquisition System

DI: BCAI00000-01717-0200-00002 REV 00
ATTACHMENT IV Date: 2/26/97 Page: IV-8 of IV-26

problem summary

run terminated when it had used 100 minutes of computer time.

MGDS waste package and drift wall primary gamma analysis

02/01/97 10:31:36
probid = 02/01/97 08:48:55

photon creation	tracks	weight (per source particle)	energy	photon loss	tracks	weight (per source particle)	energy
source	2719456	1.0025E+00	6.4455E-01	escape	393	4.0579E-06	1.4077E-06
weight window	0	0.	0.	energy cutoff	0	0.	0.
cell importance	617317	4.1588E-02	2.5142E-02	time cutoff	0	0.	0.
weight cutoff	0	0.	0.	weight window	0	0.	0.
energy importance	0	8.4963E-01	7.2837E-02	cell importance	194479	4.1590E-02	2.5165E-02
dxtran	0	0.	0.	weight cutoff	0	0.	0.
forced collisions	0	0.	0.	energy importance	2479616	8.5147E-01	7.3027E-02
exp. transform	0	0.	0.	dxtran	0	0.	0.
from neutrons	0	0.	0.	forced collisions	0	0.	0.
bremstrahlung	3641111	7.1354E-01	1.6323E-02	exp. transform	0	0.	0.
p-annihilation	41530	4.3440E-04	2.2143E-04	compton scatter	0	0.	1.9472E-01
electron x-rays	0	0.	0.	capture	7682571	3.1348E+00	5.4974E-01
1st fluorescence	2708589	1.1575E+00	7.9662E-02	pair production	20765	2.1720E-04	3.3422E-04
2nd fluorescence	649821	2.6297E-01	4.2474E-03				
total	10377824	4.0281E+00	8.4299E-01	total	10377824	4.0281E+00	8.4299E-01

number of photons banked	4381752	average lifetime, shakes	cutoffs
photon tracks per source particle	3.8161E+00	escape	tco 1.0000E-34
photon collisions per source particle	5.0623E+00	capture	eco 1.0000E-03
total photon collisions	13766638	capture or escape	wc1 -5.0000E-01
		any termination	wc2 -2.5000E-01

computer time so far in this run	102.67 minutes	maximum number ever in bank	9
computer time in acrun	100.01 minutes	bank overflows to backup file	0
source particles per minute	2.7193E+04	field length	0
random numbers generated	155919541	most random numbers used was	1822 in history 1762783

range of sampled source weights = 5.1931E-03 to 7.5229E+00

source efficiency = 1.0000 in cell 101

source efficiency = 1.0000 in cell 102

source efficiency = 1.0000 in cell 103

source efficiency = 1.0000 in cell 104

source efficiency = 1.0000 in cell 105

lphoton activity in each cell

print table 126

cell	tracks entering	population	collisions	collisions * weight (per history)	number weighted energy	flux weighted energy	average track weight (relative)	average track sfp (cm)
1 101	193247	426645	688046	4.5891E-01	6.3067E-01	6.3067E-01	2.4359E-01	2.6484E+00
2 102	444506	957011	1516514	9.5247E-01	6.2951E-01	6.2951E-01	3.2173E-01	2.6429E+00
3 103	686020	1394528	2100752	9.2222E-01	6.2948E-01	6.2948E-01	3.2212E-01	2.6434E+00
4 104	977651	1964465	2929410	1.0119E+00	6.2808E-01	6.2808E-01	3.5416E-01	2.6367E+00
5 105	1293476	2190589	3391835	8.1543E-01	6.2220E-01	6.2220E-01	1.4939E-01	2.6091E+00
6 1	298477	348571	568253	8.6943E-02	5.0347E-01	5.0347E-01	3.0937E-01	1.3708E+00
7 111	180719	168883	201	3.4027E-05	4.5826E-01	4.5826E-01	2.8232E-01	8.7377E+03
8 2	346538	393728	720016	4.7305E-02	4.3784E-01	4.3784E-01	2.6136E-01	1.2256E+00
9 3	322991	399386	1078843	2.6528E-02	4.1399E-01	4.1399E-01	2.0083E-01	1.2480E+00
10 4	196631	238837	639669	2.6263E-03	4.2503E-01	4.2503E-01	1.2912E-01	1.2603E+00
11 8	33377	30546	252	5.1820E-07	4.3374E-01	4.3374E-01	1.0618E-01	8.4542E+03
12 81	35288	30503	253	8.6687E-07	3.8523E-01	3.8523E-01	1.1574E-01	8.0047E+03
13 82	37872	30475	419	1.3727E-06	3.4514E-01	3.4514E-01	1.2206E-01	7.6381E+03
14 9	39711	30428	61	2.3713E-07	3.2047E-01	3.2047E-01	1.2762E-01	7.4096E+03
15 10	35697	33868	124794	4.9319E-04	2.9246E-01	2.9246E-01	1.2780E-01	3.7685E+00
16 11	2073	2181	7320	9.0019E-05	2.9421E-01	2.9421E-01	1.0631E-01	1.7569E+00
total	5124294	8840644	13766638	4.3249E+00				

lally 42

nps = 2719456

surface gamma dose rates--rad(Si)/hr

tally type 2 particle flux averaged over a surface.
tally for photons

areas

surface:	4	8	81	82	9
	5.11765E+03	8.04248E+03	1.10584E+04	1.53938E+04	1.60221E+04

multiplier bin:	1.89200E+09	7	-5	-6	81	82	9			
surface:	4	8	81	82	9					
energy										
4.5000E-02	2.10559E-01	0.7143	8.41059E-02	0.5971	2.46094E-02	0.3344	6.89756E-02	0.3837	6.17215E-02	0.3561
1.0000E-01	4.66021E-01	0.1410	1.02184E+00	0.1779	9.80875E-01	0.1603	1.34705E+00	0.2473	1.14156E+00	0.1238
4.5000E-01	8.61748E+00	0.0408	5.28902E+00	0.0422	4.43590E+00	0.0416	3.81133E+00	0.0379	3.98065E+00	0.0736
7.0000E-01	6.47151E+00	0.0376	3.66544E+00	0.0397	2.60221E+00	0.0401	1.84614E+00	0.0403	1.77290E+00	0.0403
1.0000E+00	5.26585E+00	0.0241	3.11171E+00	0.0243	2.22334E+00	0.0243	1.57930E+00	0.0244	1.51626E+00	0.0244
1.5000E+00	5.64525E+00	0.0171	3.43956E+00	0.0171	2.46585E+00	0.0172	1.75379E+00	0.0172	1.68364E+00	0.0172
2.0000E+00	1.91770E-01	0.0324	1.17358E-01	0.0325	8.44095E-02	0.0325	6.00871E-02	0.0326	5.77066E-02	0.0326
3.0000E+00	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000
total	2.68684E+01	0.0196	1.67290E+01	0.0226	1.28172E+01	0.0241	1.04667E+01	0.0402	1.02144E+01	0.0362

lanalysis of the results in the tally fluctuation chart bin (tfc) for tally 42 with nps = 2719456 print table 160

normed average tally per history = 2.68684E+01
estimated tally relative error = 0.0196
relative error from zero tallies = 0.0073
number of nonzero history tallies = 18793
history number of largest tally = 2082275
(largest tally)/(average tally) = 1.90373E+04
(confidence interval shift)/mean = 0.0011

unnormed average tally per history = 1.37503E+05
estimated variance of the variance = 0.0288
relative error from nonzero scores = 0.0182
efficiency for the nonzero tallies = 0.0069
largest unnormalized history tally = 2.61769E+09
(largest tally)/(avg nonzero tally) = 1.31559E+02
shifted confidence interval center = 2.68991E+01

if the largest history score sampled so far were to occur on the very next history, the ttc bin quantities would change as follows:

estimated quantities	value at nps	value at nps+1	value(nps+1)/value(nps)-1.
mean	2.68684E+01	2.70565E+01	0.007000
relative error	1.95610E-02	2.06114E-02	0.054719
variance of the variance	2.87795E-02	3.55035E-02	0.233640
shifted center	2.68991E+01	2.69063E+01	0.000268
figure of merit	2.61328E+01	2.34916E+01	-0.101069

the estimated inverse power slope of the 200 largest tallies starting at 1.93179E+08 is 4.3613
the history score probability density function appears to have an unsampled region at the largest history scores: please examine.

results of 10 statistical checks for the estimated answer for the tally fluctuation chart (ttc) bin of tally 42

ttc bin behavior	--mean-- behavior	-----relative error-----			----variance of the variance----			--figure of merit--		-pdf-slope
		value	decrease	decrease rate	value	decrease	decrease rate	value	behavior	
desired	random	<0.10	yes	1/sqrt(nps)	<0.10	yes	1/nps	constant	random	>3.00
observed	random	0.02	yes	yes	0.03	yes	yes	constant	random	4.36
passed?	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes

this tally meets the statistical criteria used to form confidence intervals: check the tally fluctuation chart to verify.
the results in other bins associated with this tally may not meet these statistical criteria.

estimated asymmetric confidence intervals(1,2,3 sigma): 2.6373E+01 to 2.7423E+01; 2.5847E+01 to 2.7951E+01; 2.5321E+01 to 2.8478E+01
estimated symmetric confidence intervals(1,2,3 sigma): 2.6343E+01 to 2.7394E+01; 2.5817E+01 to 2.7920E+01; 2.5292E+01 to 2.8445E+01
1status of the statistical checks used to form confidence intervals for the mean for each tally bin

tally result of statistical checks for the ttc bin (the first check not passed is listed) and error magnitude check for all bins

42 passed the 10 statistical checks for the tally fluctuation chart bin result
missed all bin error check: 45 tally bins had 5 bins with zeros and 10 bins with relative errors exceeding 0.10

the 10 statistical checks are only for the tally fluctuation chart bin and do not apply to other tally bins.

the tally bins with zeros may or may not be correct: compare the source, cutoffs, multipliers, et cetera with the tally bins.

warning. 1 of the 1 tallies had bins with relative errors greater than recommended.
1tally fluctuation charts

nps	mean	tally error	42 error	vov	slope	fom
256000	2.8356E+01	0.0598	0.0456	3.1	30	
512000	2.8638E+01	0.0498	0.1343	2.8	21	
768000	2.7637E+01	0.0386	0.0881	3.5	24	
1024000	2.7719E+01	0.0328	0.0550	4.7	25	
1280000	2.7300E+01	0.0283	0.0439	5.6	27	
1536000	2.7027E+01	0.0260	0.0349	4.5	26	
1792000	2.6986E+01	0.0237	0.0281	5.6	27	
2048000	2.6797E+01	0.0217	0.0243	5.3	28	
2304000	2.6746E+01	0.0216	0.0373	4.4	25	
2560000	2.6652E+01	0.0202	0.0327	4.4	26	
2719456	2.6868E+01	0.0196	0.0288	4.4	26	

dump no. 8 on file runtpe nps = 2719456 coll = 13766638 ctm = 100.01 nrm = 155919541

3 warning messages so far.

run terminated when it had used 100 minutes of computer time.

computer time = 102.69 minutes

mcnp version 4a 10/01/93

02/01/97 10:31:37

probid = 02/01/97 08:48:55

IV.2 INPUT AND OUTPUT FILES FOR CASE II (Neutron, Unshielded, Intact WP)

lmcnp version 4a ld=10/01/93 02/07/97 08:49:42
.....
inp=infwp1na

probid = 02/07/97 08:49:42

```
1- MGDS waste package and drift wall neutron analysis
2- c neutrons from 21 PWR fuel assemblies in waste package
3- c 48086 MWD/MTU, 4.2% initial enrichment and 10 years old
4- c infinite axial height model
5- c maximum waste package od=2.0 m
6- c drift inside diameter=5.1 m
7- c evaluation of radiation environment for electronic box
8- c intact waste package
9- c .....
10- c fuel region (homogenized, divided in 5 cells for source biasing)
11- 101 1 -3.0431 -101 12 -13
12- 102 1 -3.0431 101 -102 12 -13
13- 103 1 -3.0431 102 -103 12 -13
14- 104 1 -3.0431 103 -104 12 -13
15- 105 1 -3.0431 104 -105 12 -13
16- c liner for fuel basket on the outside
17- 1 4 -8.0038 105 -1 12 -13
18- c WP radial gap
19- 111 5 -0.001225 1 -111 12 -13
20- c WP inner barrier (2 cm)
21- 2 2 -6.14 111 -2 12 -13
22- c WP outer barriers (10 cm total)
23- 3 3 -7.832 2 -3 12 -13
24- 4 3 -7.832 3 -4 12 -13
25- c air space between waste package and drift
26- 8 5 -0.001225 4 -8 12 -13
27- 81 5 -0.001225 8 -81 12 -13
28- 82 5 -0.001225 81 -82 12 -13
29- 9 5 -0.001225 82 -9 12 -13
30- c drift wall (-30 cm modeled)
31- 10 6 -2.22 9 -10 12 -13
32- 11 6 -2.22 10 -11 12 -13
33- c zero importance cell
34- 12 0 11:-12:13
35-
36- 101 cz 20.0
37- 102 cz 35.0
38- 103 cz 45.0
39- 104 cz 54.0
40- 105 cz 61.0
41- 1 cz 62.68
42- 111 cz 69.45
43- 2 cz 71.45
44- 3 cz 76.45
45- 4 cz 81.45
46- 8 cz 128.0 $-11 in. from max. WP envelope
47- 81 cz 176.0 $-30 in. from max. WP envelope
48- 82 cz 245.0
49- 9 cz 255.0
50- 10 cz 270.0
51- 11 cz 285.0
52- *12 pz 0.0
53- *13 pz 10.0
54-
55- c active fuel region (smear density 3.0431 g/cc)
56- m1 7014 -0.00005
57- 8016 -0.10540
58- 24000 -0.00017
59- 26000 -0.00035
60- 40000 -0.17140
61- 50000 -0.00244
62- 92235 -0.00523
63- 92236 -0.00419
64- 92238 -0.70508
65- 94239 -0.00359
66- 94240 -0.00129
67- 94241 -0.00082
68- c alloy 825 (8.14 g/cc)
69- m2 6000 -0.0005
70- 13027 -0.0020
71- 14000 -0.0050
72- 16032 -0.0003
73- 22000 -0.0090
74- 24000 -0.2150
75- 25055 -0.0100
76- 26000 -0.2857
77- 28000 -0.4200
78- 29000 -0.0225
79- 42000 -0.0300
80- c A516 carbon steel (7.832 g/cc)
81- m3 6000 -0.0022
82- 14000 -0.00275
83- 15031 -0.00035
84- 16032 -0.00035
85- 25055 -0.0090
86- 26000 -0.98335
87- c liner [SS316B6A (vf=0.3448)+A825 (vf=0.6552), 8.0038 g/cc]
```

```

88-      m4      5010  -0.00077
89-      5011  -0.00351
90-      6000  -0.00043
91-      7014  -0.00033
92-      13027 -0.00133
93-      14000  -0.00584
94-      15031  -0.00015
95-      16032  -0.00030
96-      22000  -0.00600
97-      24000  -0.20686
98-      25055  -0.01336
99-      26000  -0.39270
100-     28000  -0.32505
101-     29000  -0.01499
102-     42000  -0.02836
103-      c      air (0.001225 g/cc)
104-     m5      7014  -0.8
105-      8016  -0.2
106-      c      dry tuff material (2.22 g/cc)
107-     m6      8016  -0.49863
108-      11023 -0.02909
109-      12000  -0.00077
110-      13027 -0.06313
111-      14000  -0.36898
112-      15031  -0.00004
113-      19000  -0.02641
114-      20000  -0.00322
115-      22000  -0.00056
116-      25055  -0.00035
117-      26000  -0.00682
118-      c      si element for tally use
119-     m7      14000  1.0
warning. material 7 is used only for tallying.
120-     mode n
121-     imp:n 1 7r 2 3 5r 1 0
122-     esp1:n 0.5 1.0-4 0.5 1.0-5 0.25 1.0-6
123-     phys:n 25.0 1.0-7
124-     sdef cel=d1 pos=0 0 5.0 rad=fcel d4 ext=d2 erg=d3 axs=0 0 1
125-     s11 1 101 102 103 104 105
126-     sp1 0.1075 0.2217 0.2150 0.2395 0.2164
127-     s12 5.0
128-     s13 0.10 0.40 0.9 1.4 1.85 3.0 6.43 20.0
129-     sp3 0.0 0.0183 0.2099 0.2341 0.1310 0.1767 0.1924 0.0376
130-     ds4 s 5 6 7 8 9
131-     s15 0.0 20.0
132-     s16 20.0 35.0
133-     s17 35.0 45.0
134-     s18 45.0 54.0
135-     s19 54.0 61.0
136-     fc22 surface neutron dose rates--rad(Si)/hr
137-     e22 6.25-7 0.1 1.0 25.0
138-     f22:n 4 8 81 82 9
139-     c multiplier=(6.567*9 neutrons/s for 21 PWR FA)(10/360.18 for 10 cm)
140-     c (1/28.0855*0.6023 for 1 g Si)(1.602-6 ergs/MeV)(3600 sec/hr)
141-     c /(100 ergs/g per rad)=2.255*2
142-     c 7=material no. 7 for silicon
143-     c 1=total neutron cross section position
144-     c 4=neutron heating number position
145-     fm22 2.255*2 7 1 -4
146-     fq0 e f
147-     ctme 30.0
148-     nps 6000000

```

warning. 2 of the materials had unnormalized fractions.
icells

print table 60

cell	mat	atom density	gram density	volume	mass	pieces	neutron importance
1	101	1	2.11253E-02	3.04310E+00	1.25664E+04	3.82407E+04	1
2	102	1	2.11253E-02	3.04310E+00	2.59181E+04	7.88715E+04	1
3	103	1	2.11253E-02	3.04310E+00	2.51327E+04	7.64814E+04	1
4	104	1	2.11253E-02	3.04310E+00	2.79916E+04	8.51812E+04	1
5	105	1	2.11253E-02	3.04310E+00	2.52898E+04	7.69595E+04	1
6	1	4	8.76062E-02	8.00380E+00	6.52768E+03	5.22462E+04	1
7	111	5	5.13692E-05	1.22500E-03	2.81022E+04	3.44252E+01	1
8	2	2	8.69963E-02	8.14000E+00	8.85301E+03	7.20635E+04	1
9	3	3	8.54217E-02	7.83200E+00	2.32321E+04	1.81954E+05	1
10	4	3	8.54217E-02	7.83200E+00	2.48029E+04	1.94256E+05	1
11	8	5	5.13692E-05	1.22500E-03	3.06302E+05	3.75220E+02	1
12	81	5	5.13692E-05	1.22500E-03	4.58421E+05	5.61566E+02	1
13	82	5	5.13692E-05	1.22500E-03	9.12601E+05	1.11794E+03	1
14	9	5	5.13692E-05	1.22500E-03	1.57080E+05	1.92423E+02	1
15	10	6	6.54011E-02	2.22000E+00	2.47400E+05	5.49229E+05	1
16	11	6	6.54011E-02	2.22000E+00	2.61538E+05	5.80613E+05	1
17	12	0	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0

total 2.55176E+06 1.98838E+06

minimum source weight = 1.0000E+00 maximum source weight = 1.0000E+00

2 warning messages so far.
1cross-section tables

print table 100

table length

tables from file rmccs2

5010.50c	9587	njoy	(1305)	79/09/10.
6000.50c	16126	njoy	(1306)	79/07/31.
7014.50c	22772	njoy	(1275)	79/09/08.
8016.50c	23669	njoy	(1276)	05/14/81
11023.51c	34325	njoy	(1311)	03/08/80
12000.51c	34240	njoy	(1312)	03/13/80
13027.50c	22891	njoy	(1313)	79/09/08.
14000.51c	42481	njoy	(1314)	03/13/80
15031.51c	2779	njoy	(1315)	03/07/80
16032.51c	2680	njoy	(1316)	03/07/80
19000.51c	7892	njoy	(1150)	03/08/80
20000.51c	21003	njoy	(1320)	03/08/80
22000.51c	14953	njoy	(1322)	03/08/80
24000.50c	89104	njoy	(1324)	79/06/21.
25055.51c	14781	njoy	(1325)	03/08/80
26000.55c	81511	njoy	(260)	10/21/82
28000.50c	82267	njoy	(1328)	79/06/21.
29000.50c	22473	njoy	(1329)	02/05/80
40000.51c	12250	njoy	(1340)	03/07/80
42000.51c	3899	njoy	(1321)	03/07/80
92235.50c	38453	njoy	(1395)	79/09/12.

warning. nubar of 92236.51c may be either prompt or total.

92236.51c	5696	njoy	(1396)	03/10/80
92238.50c	57153	njoy	(1398)	79/09/13.
94239.55c	67551	njoy	(1399)	02/21/85
94240.50c	36184	njoy	(1380)	79/09/13.
94241.51c	6697	njoy	(1381)	03/07/80

prompt nu (1395) 79/09/12.

tables from file newxs2

5011.56c 28379 06/28/88

tables from file endl852

50000.35c 2380 sa=50000 endl-85 85/04/24 t=0k (48) 86/02/01

total 804176

any neutrons with energy greater than emax = 2.50000E+01 from the source or from a collision will be resampled.

neutron cross sections outside the range from 0.0000E+00 to 2.5000E+01 mev are expunged.

warning. neutron energy cutoff is below some cross-section tables.
1decimal words of dynamically allocated storage

general	19772
tallies	6808
bank	6403
cross sections	804176
total	835931

.....

dump no.	1	on file runtime	nps =	0	coll =	0	ctm =	0.00	nrn =	0
----------	---	-----------------	-------	---	--------	---	-------	------	-------	---

4 warning messages so far.

.....

dump no.	2	on file runtime	nps =	8783	coll =	2221609	ctm =	15.01	nrn =	20607177
----------	---	-----------------	-------	------	--------	---------	-------	-------	-------	----------

1problem summary

run terminated when it had used 30 minutes of computer time.

MGDS waste package and drift wall neutron analysis

probid = 02/07/97 09:20:38
02/07/97 08:49:42

neutron creation	tracks	weight (per source particle)	energy	neutron loss	tracks	weight (per source particle)	energy
source	17567	1.0000E+00	2.4372E+00	escape	8294	4.5999E-01	2.1470E-02
weight window	0	0.	0.	energy cutoff	0	0.	0.
cell importance	118073	2.1544E-00	3.4053E-01	time cutoff	0	0.	0.
weight cutoff	0	1.2382E-01	7.5196E-03	weight window	0	0.	0.
energy importance	403	2.8022E-01	1.2672E-05	cell importance	109931	2.1438E-00	3.4694E-01
dxtran	0	0.	0.	weight cutoff	11014	1.2017E-01	7.0447E-03
forced collisions	0	0.	0.	energy importance	12683	2.7559E-01	1.2660E-05
exp. transform	0	0.	0.	dxtran	0	0.	0.
upscattering	0	0.	1.7383E-08	forced collisions	0	0.	0.
(n,xn)	514	2.5017E-02	3.9201E-02	exp. transform	0	0.	0.
fission	9125	3.8613E-01	7.9086E-01	downscattering	0	0.	2.5734E+00
total	145682	3.9696E+00	3.6153E+00	capture	203	8.2001E-01	1.7104E-01
				loss to (n,xn)	237	1.1392E-02	1.5541E-01
				loss to fission	3320	1.3858E-01	3.4001E-01
				total	145682	3.9696E+00	3.6153E+00

number of neutrons banked	105033	average lifetime, shakes	cutoffs
neutron tracks per source particle	8.2929E+00	escape	tco 1.0000E+34
neutron collisions per source particle	2.5246E+02	capture	eco 0.0000E+00
total neutron collisions	4434925	capture or escape	wc1 -5.0000E-01
net multiplication	1.2612E+00 0.0053	any termination	wc2 -2.5000E-01

Title: Performance Confirmation
Data Acquisition System

DI: BCAI00000-01717-0200-00002 REV 00
ATTACHMENT IV Date: 2/26/97Page: IV-13 of IV-26

computer time so far in this run 30.93 minutes maximum number ever in bank 24
computer time in screen 30.01 minutes bank overflows to backup file 0
source particles per minute 5.8546E+02 field length 0
random numbers generated 41101579 most random numbers used was 42920 in history 2573

range of sampled source weights = 1.0000E+00 to 1.0000E+00

source efficiency = 1.0000 in cell 101

source efficiency = 1.0000 in cell 102

source efficiency = 1.0000 in cell 103

source efficiency = 1.0000 in cell 104

source efficiency = 1.0000 in cell 105

neutron activity in each cell

print table 126

cell	tracks entering	population	collisions	collisions * weight (per history)	number weighted energy	flux weighted energy	average track weight (relative)	average track mfp (cm)
1	101	29543	11760	161141	6.0494E+00	1.1748E-01	5.0441E-01	7.7929E-01
2	102	75076	18493	305054	1.1468E+01	1.1312E-01	5.0788E-01	6.8087E-01
3	103	97336	23141	262614	9.9023E+00	1.0712E-01	5.1681E-01	6.8350E-01
4	104	105129	27251	255478	9.6131E+00	9.6705E-02	5.1140E-01	6.8121E-01
5	105	104692	30200	199857	7.4874E+00	7.8410E-02	4.8761E-01	6.7767E-01
6	1	93530	31869	213748	7.0850E+00	5.4653E-02	4.1441E-01	6.7822E-01
7	111	89079	30676	314	1.1037E-02	4.3538E-02	1.7457E-01	6.8254E-01
8	2	85588	18014	244035	8.3825E+00	1.3201E-02	1.5461E-01	6.9109E-01
9	3	132240	79236	582791	1.0623E+01	1.6352E-02	2.9919E-01	7.1269E-01
10	4	138744	80338	615009	8.6204E+00	5.2567E-03	2.2458E-01	7.6169E-01
11	8	134611	57198	3525	5.8774E-02	1.5679E-03	1.4495E-01	8.4127E-01
12	81	179114	58503	4960	8.1483E-02	1.2234E-03	1.2298E-01	8.5263E-01
13	82	235978	59588	9793	1.6237E-01	1.1132E-03	1.1123E-01	8.5603E-01
14	9	274996	59627	1772	2.8926E-02	1.0939E-03	1.0622E-01	8.5689E-01
15	10	216567	86669	1393731	2.3470E+01	6.3593E-04	7.4580E-02	8.9303E-01
16	11	29078	23541	181103	9.7620E+00	2.8230E-04	3.9874E-02	9.5918E-01
total	2021301	716104	4434925	1.1281E+02				

l tally 22 nps = 17567

surface neutron dose rates--rad(Si)/hr

tally type 2 particle flux averaged over a surface.

tally for neutrons

areas

surface: 4 8 81 82 9
5.11765E+03 8.04248E+03 1.10584E+04 1.53938E+04 1.60221E+04

multiplier bin:	2.25500E+02	7	1	-4	81	82	9
surface:	4		8				
energy							
6.2500E-07	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00
1.0000E-01	2.37195E-04	0.0187	2.04650E-04	0.0195	2.00583E-04	0.0199	1.94539E-04
1.0000E+00	3.75515E-03	0.0149	2.60558E-03	0.0160	2.29246E-03	0.0157	2.12646E-03
2.5000E+01	1.05272E-03	0.0419	6.33481E-04	0.0432	4.97352E-04	0.0416	4.19203E-04
total	5.04507E-03	0.0151	3.46371E-03	0.0156	2.99039E-03	0.0151	2.74020E-03

analysis of the results in the tally fluctuation chart bin (tfc) for tally 22 with nps = 17567 print table 160

normed average tally per history = 5.04507E-03
estimated tally relative error = 0.0151
relative error from zero tallies = 0.0048

unnormed average tally per history = 2.58189E+01
estimated variance of the variance = 0.0027
relative error from nonzero scores = 0.0143

number of nonzero history tallies = 12538
history number of largest tally = 5246
(largest tally)/(average tally) = 3.58802E+01

efficiency for the nonzero tallies = 0.7137
largest unnormalized history tally = 9.26389E+02
(largest tally)/(avg nonzero tally) = 2.56086E+01

(confidence interval shift)/mean = 0.0003

shifted confidence interval center = 5.04653E-03

if the largest history score sampled so far were to occur on the very next history, the tfc bin quantities would change as follows:

estimated quantities	value at nps	value at nps+1	value(nps+1)/value(nps)-1.
mean	5.04507E-03	5.05508E-03	0.001985
relative error	1.50641E-02	1.51634E-02	0.006393
variance of the variance	2.85249E-03	2.85118E-03	0.074908
shifted center	5.04653E-03	5.04658E-03	0.000012
figure of merit	1.46863E-02	1.44946E-02	-0.013056

the estimated inverse power slope of the 200 largest tallies starting at 2.21604E+02 is 7.5908

the large score tail of the empirical history score probability density function appears to have no unsampled regions.

=====

results of 10 statistical checks for the estimated answer for the tally fluctuation chart (tfc) bin of tally 22

tfc bin behavior	--mean-- behavior	-----relative error----- value decrease decrease rate	----variance of the variance---- value decrease decrease rate	--figure of merit-- value behavior	-pdf- slope
desired	random	<0.10 yes 1/sqrt(nps)	<0.10 yes 1/nps	constant random	>3.00
observed	random	0.02 yes yes	0.00 yes yes	constant random	7.59
passed?	yes	yes yes yes	yes yes yes	yes yes yes	yes

.....
this tally meets the statistical criteria used to form confidence intervals: check the tally fluctuation chart to verify.
the results in other bins associated with this tally may not meet these statistical criteria.

estimated asymmetric confidence intervals(1,2,3 sigma): 4.9705E-03 to 5.1225E-03; 4.8945E-03 to 5.1986E-03; 4.8185E-03 to 5.2746E-03
estimated symmetric confidence intervals(1,2,3 sigma): 4.9691E-03 to 5.1211E-03; 4.8931E-03 to 5.1971E-03; 4.8171E-03 to 5.2731E-03
1status of the statistical checks used to form confidence intervals for the mean for each tally bin

tally result of statistical checks for the ttc bin (the first check not passed is listed) and error magnitude check for all bins

22 passed the 10 statistical checks for the tally fluctuation chart bin result
passed all bin error check: 25 tally bins had 5 bins with zeros and 0 bins with relative errors exceeding 0.10

the 10 statistical checks are only for the tally fluctuation chart bin and do not apply to other tally bins.

the tally bins with zeros may or may not be correct: compare the source, cutoffs, multipliers, et cetera with the tally bins.

Itally fluctuation charts

mps	mean	tally error	22 vov	slope	fom
1000	4.7813E-03	0.0608	0.0639	5.0	160
2000	4.8278E-03	0.0442	0.0235	5.5	154
3000	4.9777E-03	0.0350	0.0129	6.6	158
4000	5.0704E-03	0.0299	0.0081	6.8	163
5000	5.0346E-03	0.0269	0.0064	6.9	161
6000	5.0127E-03	0.0254	0.0075	6.4	151
7000	5.0153E-03	0.0235	0.0061	5.4	153
8000	5.0519E-03	0.0218	0.0051	5.4	155
9000	5.0262E-03	0.0205	0.0044	6.5	154
10000	4.9911E-03	0.0196	0.0041	6.7	153
11000	5.0075E-03	0.0190	0.0042	5.2	148
12000	4.9898E-03	0.0182	0.0040	5.9	148
13000	5.0310E-03	0.0176	0.0036	7.2	147
14000	5.0836E-03	0.0169	0.0033	9.9	146
15000	5.0737E-03	0.0163	0.0030	10.0	147
16000	5.0711E-03	0.0157	0.0028	9.0	148
17000	5.0612E-03	0.0153	0.0027	6.8	146
17567	5.0451E-03	0.0151	0.0027	7.6	147

.....
dump no. 3 on file runtime mps = 17567 coll = 4434925 ctm = 30.01 nrm = 41101579

4 warning messages so far.

run terminated when it had used 30 minutes of computer time.

computer time = 30.95 minutes

mcnp version 4a 10/01/93

02/07/97 09:20:39

probid = 02/07/97 08:49:42

IV.3 INPUT AND OUTPUT FILES FOR CASE III (Gamma, Unshielded, Breached WP)

```
lmcnp version 4a ld=10/01/93 02/01/97 10:31:39
.....
inp=infwplqb probid = 02/01/97 10:31:39

1- MGDS waste package and drift wall primary gamma analysis
2- c primary gammas from 21 PWR fuel assemblies in waste package
3- c 48086 MWD/MTU, 4.2% initial enrichment and 10 years old
4- c infinite axial height model
5- c maximum waste package od=2.0 m
6- c drift inside diameter=5.1 m
7- c evaluation of radiation environment for electronic box
8- c breached waste package: basket, inner and outer barriers removed
9- c .....
10- c fuel region (homogenized, divided in 5 cells for source biasing)
11- 101 1 -3.0431 -101 12 -13
12- 102 1 -3.0431 101 -102 12 -13
13- 103 1 -3.0431 102 -103 12 -13
14- 104 1 -3.0431 103 -104 12 -13
15- 105 1 -3.0431 104 -105 12 -13
16- c liner for fuel basket on the outside
17- 1 5 -0.001225 105 -1 12 -13
18- c WP radial gap
19- 111 5 -0.001225 1 -111 12 -13
20- c WP inner barrier (2 cm)
21- 2 5 -0.001225 111 -2 12 -13
22- c WP outer barriers (10 cm total)
23- 3 5 -0.001225 2 -3 12 -13
24- 4 5 -0.001225 3 -4 12 -13
25- c air space between waste package and drift
26- 8 5 -0.001225 4 -8 12 -13
27- 81 5 -0.001225 8 -81 12 -13
28- 82 5 -0.001225 81 -82 12 -13
29- 9 5 -0.001225 82 -9 12 -13
30- c drift wall (-30 cm modeled)
31- 10 6 -2.22 9 -10 12 -13
32- 11 6 -2.22 10 -11 12 -13
33- c zero importance cell
34- 12 0 11:-12:13
35-
36- 101 cz 20.0
37- 102 cz 35.0
38- 103 cz 45.0
39- 104 cz 54.0
40- 105 cz 61.0
41- 1 cz 62.68
42- 111 cz 69.45
43- 2 cz 71.45
44- 3 cz 76.45
45- 4 cz 81.45
46- 8 cz 128.0 $-11 in. from max. WP envelope
47- 81 cz 176.0 $-30 in. from max. WP envelope
48- 82 cz 245.0
49- 9 cz 255.0
50- 10 cz 270.0
51- 11 cz 285.0
52- *12 pz 0.0
53- *13 pz 10.0
54-
55- c active fuel region (smear density 3.0431 g/cc)
56- m1 7014 -0.00005
57- 8016 -0.10540
58- 24000 -0.00017
59- 26000 -0.00035
60- 40000 -0.17140
61- 50000 -0.00244
62- 92235 -0.00523
63- 92236 -0.00419
64- 92238 -0.70508
65- 94239 -0.00359
66- 94240 -0.00129
67- 94241 -0.00082
68- c alloy 825 (8.14 g/cc)
69- m2 6000 -0.0005
70- warning. material 2 is not used in the problem.
71- 11027 -0.0020
72- 14000 -0.0050
73- 16032 -0.0003
74- 22000 -0.0090
75- 24000 -0.2150
76- 25055 -0.0100
77- 26000 -0.2857
78- 28000 -0.4200
79- 29000 -0.0225
80- 42000 -0.0300
81- c A516 carbon steel (7.832 g/cc)
82- m3 6000 -0.0022
83- warning. material 3 is not used in the problem.
84- 14000 -0.00275
85- 15031 -0.00035
86- 16032 -0.00035
87- 25055 -0.0090
```

```

86-      26000 -0.98535
87-      c      liner [SS31686A (vf=0.3448)+A825 (vf=0.6552), 8.0038 g/cc)
88-      m4      5010 -0.00077
warning. material 4 is not used in the problem.
89-      5011 -0.00351
90-      6000 -0.00043
91-      7014 -0.00033
92-      13027 -0.00133
93-      14000 -0.00584
94-      15031 -0.00015
95-      16032 -0.00030
96-      22000 -0.00600
97-      24000 -0.20686
98-      25055 -0.01336
99-      26000 -0.39270
100-     28000 -0.32505
101-     29000 -0.01499
102-     42000 -0.02836
103-     c      air (0.001225 g/cc)
104-     m5      7014 -0.8
105-     8016 -0.2
106-     c      dry tuff material (2.22 g/cc)
107-     m6      8016 -0.49863
108-     11023 -0.02909
109-     12000 -0.00077
110-     13027 -0.06513
111-     14000 -0.36898
112-     15031 -0.00004
113-     19000 -0.02641
114-     20000 -0.00322
115-     22000 -0.00056
116-     25055 -0.00035
117-     26000 -0.00682
118-     c      Si element for tally use
119-     m7      14000 1.0
warning. material 7 is used only for tallying.
120-     mode    p
121-     imp:p    0.25 0.35 0.5 0.7 1 1 1 2 4 15 4r 15 4 0
122-     esplt:p 0.5 0.25 0.5 0.1
123-     phys:p   3.0
124-     sdef     cel=d1 pos=0 0 5.0 rad=fcel d4 ext=d2 erg=d3 axs=0 0 1
125-     sil      1 101 102 103 104 105
126-     spl      0.1075 0.2217 0.2150 0.2395 0.2164
127-     sbl      0.5 1.0 1.5 2.0 3.0
128-     si2      5.0
129-     si3      0.45 0.70 1.0 1.5 2.0
130-     sp3      0.0 0.8484 0.0826 0.0681 0.0009
131-     sb3      0.0 0.2 0.1 0.6 0.1
132-     ds4      s 5 6 7 8 9
133-     si5      0.0 20.0
134-     si6      20.0 35.0
135-     si7      35.0 45.0
136-     si8      45.0 54.0
137-     si9      54.0 61.0
138-     fc42     surface gamma dose rates--rad(Si)/hr
139-     e42      0.045 0.1 0.45 0.70 1.0 1.5 2.0 3.0
140-     f42:p    4 8 81 82 9
141-     c      multiplier={5.51+16 photons/s for 0.45 - 2.0 MeV}(10/360.18 for 10 cm)
142-     c      (1/28.0855*0.6023 for 1 g Si)(1.602-6 ergs/MeV)(3600 sec/hr)
143-     c      /(100 ergs/g per rad)=1.892+9
144-     c      7=material no. 7 for silicon
145-     c      -5=total photon cross section position
146-     c      -6=heating number position
147-     fm42     1.892+9 7 -3 -6
148-     fq0      e f
149-     ctme     50.0
150-     nps      6000000

```

warning. 1 of the materials had unnormalized fractions.
icells

print table 60

cell	mat	atom density	gram density	volume	mass	photon pieces importance
1	101	1	2.11253E-02	3.04310E+00	1.25664E+04	3.82407E+04
2	102	1	2.11253E-02	3.04310E+00	2.59181E+04	7.88715E+04
3	103	1	2.11253E-02	3.04310E+00	2.51327E+04	7.64814E+04
4	104	1	2.11253E-02	3.04310E+00	2.79916E+04	8.51812E+04
5	105	1	2.11253E-02	3.04310E+00	2.52898E+04	7.69595E+04
6	1	5	5.13692E-05	1.22500E-03	6.52768E+03	7.99640E+00
7	111	5	5.13692E-05	1.22500E-03	2.81022E+04	3.44252E+01
8	2	5	5.13692E-05	1.22500E-03	8.85301E+03	1.08449E+01
9	3	5	5.13692E-05	1.22500E-03	2.32321E+04	2.84593E+01
10	4	5	5.13692E-05	1.22500E-03	2.48029E+04	3.03835E+01
11	8	5	5.13692E-05	1.22500E-03	3.06302E+05	3.75220E+02
12	81	5	5.13692E-05	1.22500E-03	4.58421E+05	5.61566E+02
13	82	5	5.13692E-05	1.22500E-03	9.12601E+05	1.11794E+03
14	9	5	5.13692E-05	1.22500E-03	1.57080E+05	1.92423E+02
15	10	6	6.54011E-02	2.22000E+00	2.47400E+05	5.49229E+05
16	11	6	6.54011E-02	2.22000E+00	2.61538E+05	5.80613E+05
17	12	0	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

total 2.55176E+06 1.48794E+06

minimum source weight = 5.1931E-03 maximum source weight = 7.5229E+00

Title: Performance Confirmation
Data Acquisition System

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3 warning messages so far.
1 across-section tables

print table 100

table length

tables from file mcpl1b2

7000.01p	389	12/13/82
8000.01p	389	12/13/82
11000.01p	401	12/13/82
12000.01p	409	12/13/82
13000.01p	409	12/13/82
14000.01p	409	12/13/82
15000.01p	409	12/13/82
19000.01p	409	12/13/82
20000.01p	417	12/13/82
22000.01p	417	12/13/82
24000.01p	417	12/13/82
25000.01p	417	12/13/82
26000.01p	417	12/13/82
40000.01p	461	12/13/82
50000.01p	461	12/13/82
92000.01p	533	12/13/82
94000.01p	533	12/13/82
total	7297	

maximum photon energy set to 100.0 mev (maximum electron energy)

tables from file e12

7000.01e	478	11/16/88
8000.01e	478	11/16/88
11000.01e	478	11/16/88
12000.01e	478	11/16/88
13000.01e	478	11/16/88
14000.01e	478	11/16/88
15000.01e	478	11/16/88
19000.01e	478	11/16/88
20000.01e	478	11/16/88
22000.01e	478	11/16/88
24000.01e	478	11/16/88
25000.01e	478	11/16/88
26000.01e	478	11/16/88
40000.01e	478	11/16/88
50000.01e	478	11/16/88
92000.01e	478	11/16/88
94000.01e	478	11/16/88

1 decimal words of dynamically allocated storage

general	416164
tallies	7056
bank	6403
cross sections	7297
total	435692

.....
dump no. 1 on file runtpe nps = 0 coll = 0 ctm = 0.00 nrm = 0

3 warning messages so far.

.....
dump no. 2 on file runtpe nps = 121072 coll = 1322428 ctm = 15.00 nrm = 19897133

.....
dump no. 3 on file runtpe nps = 241340 coll = 2649338 ctm = 30.00 nrm = 39812633

.....
dump no. 4 on file runtpe nps = 362041 coll = 3978424 ctm = 45.02 nrm = 59745595

1 problem summary

run terminated when it had used 50 minutes of computer time.

MGDS waste package and drift wall primary gamma analysis

02/01/97 11:23:06
probid = 02/01/97 10:31:39

photon creation	tracks	weight (per source particle)	energy	photon loss	tracks	weight (per source particle)	energy
source	402268	1.0050E+00	6.4460E-01	escape	11458	1.3924E-03	5.4627E-04
weight window	0	0.	0.	energy cutoff	0	0.	0.
cell importance	631342	5.4666E-02	2.9178E-02	time cutoff	0	0.	0.
weight cutoff	0	0.	0.	weight window	0	0.	0.
energy importance	0	8.5066E-01	7.3362E-02	cell importance	196330	5.4402E-02	2.9308E-02
dxtran	0	0.	0.	weight cutoff	0	0.	0.
forced collisions	0	0.	0.	energy importance	645539	8.5995E-01	7.4115E-02
exp. transform	0	0.	0.	dxtran	0	0.	0.
from neutrons	0	0.	0.	forced collisions	0	0.	0.
bremsstrahlung	581299	7.0777E-01	1.6240E-02	exp. transform	0	0.	0.
				compton scatter	0	0.	1.9656E-01
				capture	1249563	3.1102E+00	5.4611E-01

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p-annihilation	6768	4.2623E-04	2.1672E-04	pair production	3384	2.1311E-04	3.2739E-04
electron x-rays	0	0	0				
1st fluorescence	389485	1.1441E+00	7.9124E-02				
2nd fluorescence	95112	2.6357E-01	4.2443E-03				
total	2106274	4.0262E+00	8.4696E-01	total	2106274	4.0262E+00	8.4696E-01

number of photons banked	936028	average lifetime, shakes	cutoffs		
photon tracks per source particle	5.2360E+00	escape	9.2125E-01	tco	1.0000E+34
photon collisions per source particle	1.0988E+01	capture	2.5467E-02	eco	1.0000E-03
total photon collisions	4420248	capture or escape	2.5867E-02	wc1	-5.0000E-01
		any termination	3.5507E-02	wc2	-2.5000E-01

computer time so far in this run	51.44 minutes	maximum number ever in bank	9
computer time in mcrun	50.01 minutes	bank overflows to backup file	0
source particles per minute	8.0433E+03	field length	0
random numbers generated	66367600	most random numbers used was	6711 in history 65845

range of sampled source weights = 5.1931E-03 to 7.5229E-00

source efficiency = 1.0000 in cell 101

source efficiency = 1.0000 in cell 102

source efficiency = 1.0000 in cell 103

source efficiency = 1.0000 in cell 104

source efficiency = 1.0000 in cell 105

1photon activity in each cell

print table 126

cell	tracks entering	population	collisions	collisions * weight (per history)	number weighted energy	flux weighted energy	average track weight (relative)	average track mfp (cm)
1 101	28746	63344	101900	4.6103E-01	6.3140E-01	6.3140E-01	2.4317E-01	2.6530E+00
2 102	66126	142592	226092	9.5570E-01	6.2980E-01	6.2980E-01	3.2120E-01	2.6454E+00
3 103	101752	206617	310888	9.1641E-01	6.3015E-01	6.3015E-01	3.2198E-01	2.6463E+00
4 104	144160	289766	431849	1.0103E+00	6.2768E-01	6.2768E-01	3.5568E-01	2.6349E+00
5 105	186347	352227	491221	7.9985E-01	6.2482E-01	6.2482E-01	3.4931E-01	2.6225E+00
6 1	43038	42807	11	3.9760E-05	5.9273E-01	5.9273E-01	3.3604E-01	9.8270E+03
7 111	43283	42986	35	5.8241E-05	5.7850E-01	5.7850E-01	3.4012E-01	9.7112E+03
8 2	87125	86203	30	1.7728E-05	5.7035E-01	5.7035E-01	3.4127E-01	9.6441E+03
9 3	175168	172359	118	3.4387E-05	5.5981E-01	5.5981E-01	3.4580E-01	9.5468E+03
10 4	660904	625225	428	2.8311E-05	5.5358E-01	5.5358E-01	3.4686E-01	9.4927E+03
11 8	683735	625648	4356	3.4133E-04	5.1013E-01	5.1013E-01	3.6562E-01	9.1078E+03
12 81	726465	625349	5148	4.0710E-04	4.5241E-01	4.5241E-01	3.9431E-01	8.5978E+03
13 82	785113	625279	8529	7.9971E-04	4.0256E-01	4.0256E-01	4.2154E-01	8.1611E+03
14 9	827394	624575	1457	1.3986E-04	3.7686E-01	3.7686E-01	4.3505E-01	7.9401E+03
15 10	747054	725143	2653415	2.3883E-01	3.2045E-01	3.2045E-01	4.0695E-01	3.9459E+00
16 11	53129	56723	184771	4.7239E-02	2.7284E-01	2.7284E-01	3.0332E-01	3.6522E+00

total 5359539 5306843 4420248 4.4313E+00

tally 42 nps = 402268

surface gamma dose rates--rad(Si)/hr

tally type 2 particle flux averaged over a surface.
tally for photons

areas	surface:	4	8	81	82	9
		5.11765E+03	8.04248E+03	1.10584E+04	1.53938E+04	1.60221E+04

multiplier bin:	1.89200E+09	7	-5	-6	81	82	9				
surface:	4	8	81	82	9						
energy	4.5000E-02	4.32686E+01	0.2604	4.28827E+01	0.1799	4.63340E-01	0.2802	3.25354E+01	0.1719	3.02738E+01	0.1592
	1.0000E-01	4.26580E+02	0.0708	4.70997E+02	0.0512	5.03741E+02	0.0465	5.10892E+02	0.0383	5.19908E+02	0.0394
	4.5000E-01	1.60267E+03	0.0312	1.44317E+03	0.0239	1.41275E+03	0.0212	1.48408E+03	0.0190	1.49119E+03	0.0187
	7.0000E-01	8.79696E+03	0.0183	5.17171E+03	0.0182	3.68052E+03	0.0181	2.63469E+03	0.0182	2.53369E+03	0.0182
	1.0000E+00	2.13940E+03	0.0183	1.25681E+03	0.0181	8.95787E+02	0.0180	6.38950E+02	0.0179	6.14002E+02	0.0179
	1.5000E+00	2.94128E+03	0.0076	1.72143E+03	0.0076	1.22134E+03	0.0075	8.64724E+02	0.0075	8.29678E+02	0.0075
	2.0000E+00	5.75900E+01	0.0169	3.37065E+01	0.0168	2.39483E+01	0.0168	1.69405E+01	0.0168	1.62516E+01	0.0168
	3.0000E+00	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000
total	1.60077E+04	0.0118	1.01407E+04	0.0120	7.78442E+03	0.0123	6.18281E+03	0.0125	6.03499E+03	0.0126	

analysis of the results in the tally fluctuation chart bin (tfc) for tally 42 with nps = 402268 print table 160

normed average tally per history = 1.60077E+04
estimated tally relative error = 0.0118
relative error from zero tallies = 0.0047

unnormed average tally per history = 8.19221E+07
estimated variance of the variance = 0.0012
relative error from nonzero scores = 0.0108

number of nonzero history tallies = 40308
history number of largest tally = 194465
(largest tally)/(average tally) = 7.06108E+02

efficiency for the nonzero tallies = 0.1002
largest unnormalized history tally = 5.78459E+10
(largest tally)/(avg nonzero tally) = 7.07533E+01

(confidence interval shift)/mean = 0.0001

shifted confidence interval center = 1.60101E+04

if the largest history score sampled so far were to occur on the very next history, the tfc bin quantities would change as follows:

estimated quantities	value at nps	value at nps+1	value(nps+1)/value(nps)-1.
mean	1.60077E+04	1.60358E+04	0.001753
relative error	1.18316E-02	1.19397E-02	0.009143
variance of the variance	1.16763E-03	1.57912E-03	0.352413
shifted center	1.60101E+04	1.60103E+04	0.000016

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figure of merit 1.42836E+02 1.40259E+02 -0.018038

the estimated inverse power slope of the 200 largest tallies starting at 1.01846E+10 is 8.6081
the history score probability density function appears to have an unsampled region at the largest history scores: please examine.

results of 10 statistical checks for the estimated answer for the tally fluctuation chart (tfc) bin of tally 42

tfc bin	--mean-- behavior	value	relative decrease	error-- decrease rate	value	variance of the decrease	variance-- decrease rate	--figure of merit-- value	behavior	-pdf- slope
desired	random	<0.10	yes	1/sqrt(nps)	<0.10	yes	1/nps	constant	random	>3.00
observed	random	0.01	yes	yes	0.00	yes	yes	constant	random	8.61
passed?	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes

this tally meets the statistical criteria used to form confidence intervals: check the tally fluctuation chart to verify.
the results in other bins associated with this tally may not meet these statistical criteria.

estimated asymmetric confidence intervals(1,2,3 sigma): 1.5821E+04 to 1.6200E+04; 1.5631E+04 to 1.6389E+04; 1.5442E+04 to 1.6578E+04
estimated symmetric confidence intervals(1,2,3 sigma): 1.5818E+04 to 1.6197E+04; 1.5629E+04 to 1.6387E+04; 1.5440E+04 to 1.6576E+04
status of the statistical checks used to form confidence intervals for the mean for each tally bin

tally result of statistical checks for the tfc bin (the first check not passed is listed) and error magnitude check for all bins
42 passed the 10 statistical checks for the tally fluctuation chart bin result
missed all bin error check: 45 tally bins had 5 bins with zeros and 5 bins with relative errors exceeding 0.10

the 10 statistical checks are only for the tally fluctuation chart bin and do not apply to other tally bins.

the tally bins with zeros may or may not be correct: compare the source, cutoffs, multipliers, et cetera with the tally bins.

warning. 1 of the 1 tallies had bins with relative errors greater than recommended.
tally fluctuation charts

nps	mean	tally error	vov	slope	fom
32000	1.6104E+04	0.0400	0.0073	5.9	157
64000	1.6176E+04	0.0292	0.0045	4.2	148
96000	1.6058E+04	0.0241	0.0032	4.1	145
128000	1.6039E+04	0.0208	0.0023	6.1	145
160000	1.6045E+04	0.0186	0.0018	5.6	146
192000	1.5956E+04	0.0170	0.0015	6.1	144
224000	1.6012E+04	0.0160	0.0027	5.9	141
256000	1.6079E+04	0.0149	0.0022	6.7	142
288000	1.5938E+04	0.0140	0.0019	7.9	143
320000	1.5915E+04	0.0133	0.0016	9.1	143
352000	1.5993E+04	0.0127	0.0014	8.0	142
384000	1.6018E+04	0.0121	0.0013	8.8	142
402268	1.6008E+04	0.0118	0.0012	8.6	143

dump no. 5 on file runtime nps = 402268 coll = 4420248 ctm = 50.01 nrm = 66367600

6 warning messages so far.

run terminated when it had used 50 minutes of computer time.

computer time = 51.46 minutes

mcnp version 4a 10/01/93

02/01/97 11:23:07

probid = 02/01/97 10:31:39

IV.4 INPUT AND OUTPUT FILES FOR CASE IV (Gamma, Shielded, Intact WP)

```
lmcnp version 4a ld=10/01/93 02/01/97 11:23:09
inp=infwpigc probid = 02/01/97 11:23:09

1- MGDS waste package and drift wall primary gamma analysis
2- c primary gammas from 21 PWR fuel assemblies in waste package
3- c 48086 MWD/MTU, 4.2% initial enrichment and 10 years old
4- c infinite axial height model
5- c maximum waste package od=2.0 m
6- c drift inside diameter=5.1 m
7- c evaluation of radiation environment for electronic box (shielded)
8- c intact waste package
9- c
10- c fuel region (homogenized, divided in 5 cells for source biasing)
11- 101 1 -3.0431 -101 12 -13
12- 102 1 -3.0431 101 -102 12 -13
13- 103 1 -3.0431 102 -103 12 -13
14- 104 1 -3.0431 103 -104 12 -13
15- 105 1 -3.0431 104 -105 12 -13
16- c liner for fuel basket on the outside
17- 1 4 -8.0038 105 -1 12 -13
18- c WP radial gap
19- 111 5 -0.001225 1 -111 12 -13
20- c WP inner barrier (2 cm)
21- 2 2 -8.14 111 -2 12 -13
22- c WP outer barriers (10 cm total)
23- 3 3 -7.832 2 -3 12 -13
24- 4 3 -7.832 3 -4 12 -13
25- c air space between waste package and electronic box
26- 8 5 -0.001225 4 -8 12 -13
27- c SS304 shielding for electronic box (parametric evaluation)
28- 801 8 -7.9 8 -801 12 -13 $1" steel
29- 802 8 -7.9 801 -802 12 -13 $2" steel
30- 803 8 -7.9 802 -803 12 -13 $3" steel
31- 804 8 -7.9 803 -804 12 -13 $4" steel
32- c air between electronic box and drift wall
33- 81 5 -0.001225 804 -81 12 -13
34- 82 5 -0.001225 81 -82 12 -13
35- 9 5 -0.001225 82 -9 12 -13
36- c drift wall (-30 cm modeled)
37- 10 6 -2.22 9 -10 12 -13
38- 11 6 -2.22 10 -11 12 -13
39- c zero importance cell
40- 12 0 11:-12:13
41-
42- 101 cz 20.0
43- 102 cz 35.0
44- 103 cz 45.0
45- 104 cz 54.0
46- 105 cz 61.0
47- 1 cz 62.68
48- 111 cz 69.45
49- 2 cz 71.45
50- 3 cz 76.45
51- 4 cz 91.45
52- 8 cz 128.0 $-11 in. from max. WP envelope
53- 801 cz 130.54
54- 802 cz 133.08
55- 803 cz 135.62
56- 804 cz 138.16
57- 81 cz 176.0 $-30 in. from max. WP envelope
58- 82 cz 245.0
59- 9 cz 255.0
60- 10 cz 270.0
61- 11 cz 285.0
62- *12 pz 0.0
63- *13 pz 10.0
64-
65- c active fuel region (smear density 3.0431 g/cc)
66- m1 7014 -0.00005
67- 8016 -0.10540
68- 24000 -0.00017
69- 26000 -0.00035
70- 40000 -0.17140
71- 50000 -0.00244
72- 92235 -0.00523
73- 92236 -0.00419
74- 92238 -0.70508
75- 94239 -0.00359
76- 94240 -0.00129
77- 94241 -0.00082
78- c alloy 825 (8.14 g/cc)
79- m2 6000 -0.0005
80- 13027 -0.0020
81- 14000 -0.0050
82- 16032 -0.0003
83- 22000 -0.0090
84- 24000 -0.2150
85- 25055 -0.0100
86- 26000 -0.2857
87- 28000 -0.4200
```

```

88-      29000 -0.0225
89-      42000 -0.0300
90-      c      A516 carbon steel (7.832 g/cc)
91-      m3      6000 -0.0022
92-      14000 -0.00275
93-      15031 -0.00035
94-      16032 -0.00035
95-      25055 -0.0090
96-      26000 -0.98535
97-      c      liner (SS316B6A (vf=0.3448)+A825 (vf=0.6352), 8.0038 g/cc)
98-      m4      5010 -0.00077
99-      5011 -0.00351
100-     6000 -0.00043
101-     7014 -0.00033
102-     13027 -0.00133
103-     14000 -0.00584
104-     15031 -0.00015
105-     16032 -0.00030
106-     22000 -0.00600
107-     24000 -0.20686
108-     25055 -0.01336
109-     26000 -0.39270
110-     28000 -0.32505
111-     29000 -0.01499
112-     42000 -0.02836
113-     c      air (0.001225 g/cc)
114-     m5      7014 -0.8
115-     8016 -0.2
116-     c      dry tuff material (2.22 g/cc)
117-     m6      8016 -0.49863
118-     11023 -0.02909
119-     12000 -0.00077
120-     13027 -0.06513
121-     14000 -0.36898
122-     15031 -0.00004
123-     19000 -0.02641
124-     20000 -0.00322
125-     22000 -0.00056
126-     25055 -0.00035
127-     26000 -0.00682
128-     c      Si element for tally use
129-     m7      14000 1.0
warning. material 7 is used only for tallying.
130-     c      SS304 (7.90 g/cc)
131-     m8      6000 -0.00080
132-     7014 -0.00100
133-     14000 -0.00750
134-     15031 -0.00045
135-     16032 -0.00030
136-     24000 -0.19000
137-     25055 -0.02000
138-     26000 -0.68745
139-     28000 -0.09250
140-     mode    p
141-     isp:p    0.25 0.35 0.5 0.7 1 1 1 2 4 15 15 30 60 120 240 4r 60 0
142-     esplt:p  0.5 0.25 0.5 0.1
143-     phys:p    3.0
144-     sdef     cel=d1 pos=0 0 5.0 rad=fcel d4 ext=d2 erg=d3 axs=0 0 1
145-     s11      1 101 102 103 104 105
146-     sp1      0.1075 0.2217 0.2150 0.2395 0.2164
147-     sb1      0.5 1.0 1.5 2.0 3.0
148-     si2      5.0
149-     si3      0.45 0.70 1.0 1.5 2.0
150-     sp3      0.0 0.8484 0.0826 0.0681 0.0009
151-     sb3      0.0 0.2 0.1 0.6 0.1
152-     ds4      s 5 6 7 8 9
153-     si5      0.0 20.0
154-     si6      20.0 35.0
155-     si7      35.0 45.0
156-     si8      45.0 54.0
157-     si9      54.0 61.0
158-     fc42     surface gamma dose rates--rad(Si)/hr
159-     e42       0.045 0.1 0.45 0.70 1.0 1.5 2.0 3.0
160-     f42:p     4 8 801 802 803 804 81 82 9
161-     c         multiplier=(5.51+16 photons/s for 0.45 - 2.0 MeV)(10/360.18 for 10 cm)
162-     c         (1/28.0855*0.6023 for 1 g Si)(1.602-6 ergs/MeV)(3600 sec/hr)
163-     c         /(100 ergs/g per rad)=1.892+9
164-     c         7=material no. 7 for silicon
165-     c         -5=total photon cross section position
166-     c         -6=heating number position
167-     fm42     1.892+9 7 -5 -6
168-     fq0      e f
169-     ctme     300.0
170-     nps      6000000

```

warning. 2 of the materials had unnormalized fractions.
1cells

print table 60

cell	mat	atom density	gram density	volume	mass	photon pieces	importance
1	101	1	2.11253E-02	3.04310E+00	1.25664E+04	3.82407E+04	1 2.5000E-01
2	102	1	2.11253E-02	3.04310E+00	2.59181E+04	7.88715E+04	1 3.5000E-01
3	103	1	2.11253E-02	3.04310E+00	2.51327E+04	7.64814E+04	1 5.0000E-01
4	104	1	2.11253E-02	3.04310E+00	2.79916E+04	8.51812E+04	1 7.0000E-01

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5	105	1	2.11253E-02	3.04310E+00	2.52898E+04	7.69595E+04	1	1.0000E+00
6	1	4	8.76062E-02	8.00380E+00	6.52768E+03	5.22462E+04	1	1.0000E+00
7	111	5	5.13692E-05	1.22500E-03	2.81022E+04	3.44252E+01	1	1.0000E+00
8	2	2	8.69963E-02	8.14000E+00	8.85301E+03	7.20635E+04	1	2.0000E+00
9	3	3	8.54217E-02	7.83200E+00	2.32321E+04	1.81954E+05	1	4.0000E+00
10	4	3	8.54217E-02	7.83200E+00	2.48029E+04	1.94256E+05	1	1.5000E+01
11	8	5	5.13692E-05	1.22500E-03	3.06302E+05	3.75220E+02	1	1.5000E+01
12	801	8	8.72184E-02	7.90000E+00	2.06306E+04	1.62982E+05	1	3.0000E+01
13	802	8	8.72184E-02	7.90000E+00	2.10359E+04	1.66184E+05	1	6.0000E+01
14	803	8	8.72184E-02	7.90000E+00	2.14413E+04	1.69386E+05	1	1.2000E+02
15	804	8	8.72184E-02	7.90000E+00	2.18467E+04	1.72589E+05	1	2.4000E+02
16	81	5	5.13692E-05	1.22500E-03	3.73467E+05	4.57497E+02	1	2.4000E+02
17	82	5	5.13692E-05	1.22500E-03	9.12601E+05	1.11794E+03	1	2.4000E+02
18	9	5	5.13692E-05	1.22500E-03	1.57080E+05	1.92423E+02	1	2.4000E+02
19	10	6	6.54011E-02	2.22000E+00	2.47400E+05	5.49229E+05	1	2.4000E+02
20	11	6	6.54011E-02	2.22000E+00	2.61538E+05	5.80613E+05	1	6.0000E+01
21	12	0	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0	0.0000E+00

total 2.55176E+06 2.65941E+06

minimum source weight = 5.1931E-03 maximum source weight = 7.5229E+00

2 warning messages so far.
1 cross-section tables

print table 100

table length

tables from file mcplib2

5000.01p	389	12/13/82
6000.01p	389	12/13/82
7000.01p	389	12/13/82
8000.01p	389	12/13/82
11000.01p	401	12/13/82
12000.01p	409	12/13/82
13000.01p	409	12/13/82
14000.01p	409	12/13/82
15000.01p	409	12/13/82
16000.01p	409	12/13/82
19000.01p	409	12/13/82
20000.01p	417	12/13/82
22000.01p	417	12/13/82
24000.01p	417	12/13/82
25000.01p	417	12/13/82
26000.01p	417	12/13/82
28000.01p	429	12/13/82
29000.01p	429	12/13/82
40000.01p	461	12/13/82
42000.01p	461	12/13/82
50000.01p	461	12/13/82
92000.01p	533	12/13/82
94000.01p	533	12/13/82
total	9803	

maximum photon energy set to 100.0 mev (maximum electron energy)

tables from file el2

5000.01e	478	11/16/88
6000.01e	478	11/16/88
7000.01e	478	11/16/88
8000.01e	478	11/16/88
11000.01e	478	11/16/88
12000.01e	478	11/16/88
13000.01e	478	11/16/88
14000.01e	478	11/16/88
15000.01e	478	11/16/88
16000.01e	478	11/16/88
19000.01e	478	11/16/88
20000.01e	478	11/16/88
22000.01e	478	11/16/88
24000.01e	478	11/16/88
25000.01e	478	11/16/88
26000.01e	478	11/16/88
28000.01e	478	11/16/88
29000.01e	478	11/16/88
40000.01e	478	11/16/88
42000.01e	478	11/16/88
50000.01e	478	11/16/88
92000.01e	478	11/16/88
94000.01e	478	11/16/88

1 decimal words of dynamically allocated storage

general	477410
callies	7504
bank	6403
cross sections	9803
total	499892

.....
dump no. 1 on file runtime nps = 0 coll = 0 ctm = 0.00 nrm = 0

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2 warning messages so far.

```

.....
dump no. 2 on file runtpe      nps = 397230      coll = 2062246      ctm = 15.01      nrm = 23313704
.....
dump no. 3 on file runtpe      nps = 793960      coll = 4121890      ctm = 30.02      nrm = 46603080
.....
dump no. 4 on file runtpe      nps = 1190720     coll = 6183863      ctm = 45.02      nrm = 69902182
.....
dump no. 5 on file runtpe      nps = 1587040     coll = 8244265      ctm = 60.02      nrm = 93191444
.....
dump no. 6 on file runtpe      nps = 1983800     coll = 10306251     ctm = 75.03      nrm = 116503983
.....
dump no. 7 on file runtpe      nps = 2381000     coll = 12367483     ctm = 90.04      nrm = 139812999
.....
dump no. 8 on file runtpe      nps = 2778240     coll = 14428687     ctm = 105.05     nrm = 163110555
.....
dump no. 9 on file runtpe      nps = 3174960     coll = 16490511     ctm = 120.05     nrm = 186421284
.....
dump no. 10 on file runtpe     nps = 3573520     coll = 18551820     ctm = 135.06     nrm = 209715004
.....
dump no. 11 on file runtpe     nps = 3970815     coll = 20614118     ctm = 150.08     nrm = 233021744
.....
dump no. 12 on file runtpe     nps = 4368758     coll = 22676516     ctm = 165.09     nrm = 256333035
.....
dump no. 13 on file runtpe     nps = 4765363     coll = 24737931     ctm = 180.10     nrm = 279632770
.....
dump no. 14 on file runtpe     nps = 5163659     coll = 26800741     ctm = 195.11     nrm = 302954073
.....
dump no. 15 on file runtpe     nps = 5560076     coll = 28862369     ctm = 210.12     nrm = 326255226
.....
dump no. 16 on file runtpe     nps = 5956293     coll = 30926029     ctm = 225.13     nrm = 349576105
.....

```

problem summary

run terminated when 6000000 particle histories were done.

MGDS waste package and drift wall primary gamma analysis

02/01/97 15:13:02
probid = 02/01/97 11:23:09

photon creation	tracks	weight (per source particle)	energy	photon loss	tracks	weight (per source particle)	energy
source	6000000	1.0009E+00	6.4465E-01	escape	338	4.6162E-08	2.2294E-08
weight window	0	0.	0.	energy cutoff	0	0.	0.
cell importance	1561004	4.1579E-02	2.5163E-02	time cutoff	0	0.	0.
weight cutoff	0	0.	0.	weight window	0	0.	0.
energy importance	0	8.4884E-01	7.2919E-02	cell importance	442745	4.1433E-02	2.5074E-02
dxtran	0	0.	0.	weight cutoff	0	0.	0.
forced collisions	0	0.	0.	energy importance	5573246	8.5049E-01	7.3079E-02
exp. transform	0	0.	0.	dxtran	0	0.	0.
from neutrons	0	0.	0.	forced collisions	0	0.	0.
bremsstrahlung	8094985	7.1346E-01	1.6341E-02	exp. transform	0	0.	0.
p-annihilation	92416	4.3346E-04	2.2129E-04	compton scatter	0	0.	1.9491E-01
electron x-rays	0	0.	0.	capture	17139027	3.1332E+00	5.4987E-01
1st fluorescence	6019138	1.1578E+00	7.9738E-02	pair production	46208	2.1673E-04	3.3420E-04
2nd fluorescence	1434021	2.6226E-01	4.2419E-03				
total	23201564	4.0253E+00	8.4327E-01	total	23201564	4.0253E+00	8.4327E-01
number of photons banked		9930869		average lifetime, shakes		cutoffs	
photon tracks per source particle		3.8669E+00		escape	8.6780E-01	tco	1.0000E+34
photon collisions per source particle		5.1923E+00		capture	8.8083E-03	eco	1.0000E-03
total photon collisions		31154094		capture or escape	8.8083E-03	wc1	-5.0000E-01
				any termination	9.2609E-03	wc2	-2.5000E-01

computer time so far in this run 229.88 minutes

maximum number ever in bank 11

Title: Performance Confirmation
Data Acquisition System

DI: BCAI00000-01717-0200-00002 REV 00
ATTACHMENT IV Date: 2/26/97Page: IV-24 of IV-26

computer time in mcrun 226.80 minutes
source particles per minute 2.6455E+04
random numbers generated 352150444

bank overflows to backup file 0
field length 0
most random numbers used was 4171 in history 704528

range of sampled source weights = 5.1931E-03 to 7.5229E-00

source efficiency = 1.0000 in cell 101

source efficiency = 1.0000 in cell 102

source efficiency = 1.0000 in cell 103

source efficiency = 1.0000 in cell 104

source efficiency = 1.0000 in cell 105

lphoton activity in each cell

print table 126

cell	tracks entering	population	collisions	collisions * weight (per history)	number weighted energy	flux weighted energy	average track weight (relative)	average track mfp (cm)
1 101	427141	942867	1521509	4.6021E-01	6.3056E-01	6.3056E-01	2.4325E-01	2.6477E+00
2 102	981428	2114071	3350722	9.4829E-01	6.3054E-01	6.3054E-01	3.1973E-01	2.6478E+00
3 103	1511864	3074384	4632149	9.2111E-01	6.2975E-01	6.2975E-01	3.2106E-01	2.6444E+00
4 104	2158029	4335163	6461984	1.0129E+00	6.2811E-01	6.2811E-01	3.5375E-01	2.6368E+00
5 105	2854283	5276223	7488829	8.1675E-01	6.2190E-01	6.2190E-01	3.4966E-01	2.6076E+00
6 1	656585	767227	1251667	8.6395E-02	5.0310E-01	5.0310E-01	3.1003E-01	1.3704E+00
7 111	397047	371333	432	2.8848E-05	4.5671E-01	4.5671E-01	2.8567E-01	8.7610E+03
8 2	761857	866258	1583623	4.7102E-02	4.3798E-01	4.3798E-01	2.6293E-01	1.2264E+00
9 3	709621	877925	2370124	2.6588E-02	4.1468E-01	4.1468E-01	2.0274E-01	1.2506E+00
10 4	432463	527049	1411706	2.6427E-03	4.2339E-01	4.2339E-01	1.3020E-01	1.2584E+00
11 8	74227	70209	510	5.8696E-07	4.4092E-01	4.4092E-01	1.0261E-01	8.5686E+03
12 801	146254	161126	330169	2.2662E-04	4.3080E-01	4.3080E-01	9.5279E-02	1.2509E+00
13 802	116262	130669	265320	7.5146E-05	4.4790E-01	4.4790E-01	8.1784E-02	1.2843E+00
14 803	91387	102633	208814	2.6653E-05	4.5751E-01	4.5751E-01	7.2982E-02	1.2978E+00
15 804	71558	79536	162944	9.1447E-06	4.6930E-01	4.6930E-01	6.5001E-02	1.3145E+00
16 81	30193	26768	173	8.3260E-09	4.3978E-01	4.3978E-01	6.6441E-02	8.4678E+01
17 82	32316	26752	324	1.7351E-08	3.9927E-01	3.9927E-01	6.9473E-02	8.1102E+03
18 9	33952	26703	57	2.8480E-09	3.6943E-01	3.6943E-01	7.2260E-02	7.8460E+03
19 10	30484	29737	107193	6.8602E-06	3.2564E-01	3.2564E-01	7.4760E-02	3.9431E+00
20 11	1715	1792	5845	1.5225E-06	2.9648E-01	2.9648E-01	6.9282E-02	3.7306E+00
total	11518666	19808625	31154094	4.3223E+00				

l tally 42 nps = 6000000

surface gamma dose rates--rad(Si)/hr

tally type 2 particle flux averaged over a surface.
tally for photons

areas

surface:	4	8	801	802	803	804	81
surface:	5.11765E+03	8.04248E+03	8.20207E+03	8.36166E+03	8.52126E+03	8.68085E+03	1.10584E+04
surface:	82	5					
	1.53938E+04	1.60221E+04					

multiplier bin:

surface:	4	7	-5	-6	801	802	803
energy	4.5000E-02	7.22547E-01	0.9076	4.78403E-02	0.6468	6.38768E-02	0.8629
4.5000E-01	2.16418E-01	0.2290	1.88186E-01	0.2484	4.15146E-02	0.1342	1.80543E-02
4.5000E-01	9.06028E+00	0.0258	6.30403E+00	0.0246	2.15828E+00	0.0240	7.07871E-01
7.0000E-01	6.34469E+00	0.0251	3.62567E+00	0.0261	1.36634E+00	0.0266	4.93325E-01
1.0000E+00	5.03528E+00	0.0155	2.98184E+00	0.0157	1.15025E+00	0.0179	4.24900E-01
1.5000E+00	5.62452E+00	0.0116	3.42850E+00	0.0116	1.25124E+00	0.0145	4.61029E-01
2.0000E+00	1.89549E-01	0.0216	1.16027E-01	0.0217	4.77042E-02	0.0257	1.89104E-02
3.0000E+00	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00	0.0000	0.00000E+00
total	2.71933E+01	0.0293	1.66923E+01	0.0134	6.07920E+00	0.0162	2.14838E+00

surface:	804	81	82	9
energy	4.5000E-02	7.31270E-04	0.4370	9.21113E-04
4.5000E-01	9.02477E-03	0.0984	9.86199E-03	0.0941
4.5000E-01	7.68179E-02	0.0428	6.02977E-02	0.0379
7.0000E-01	5.55998E-02	0.0336	3.93479E-02	0.0352
1.0000E+00	5.71647E-02	0.0261	4.28984E-02	0.0263
1.5000E+00	6.11923E-02	0.0250	4.72960E-02	0.0250
2.0000E+00	3.08858E-03	0.0401	2.40098E-03	0.0401
3.0000E+00	0.00000E+00	0.0000	0.00000E+00	0.0000
total	2.63619E-01	0.0212	2.03024E-01	0.0207

l analysis of the results in the tally fluctuation chart bin (tfc) for tally 42 with nps = 6000000 print table 160

normed average tally per history = 2.71933E+01
estimated tally relative error = 0.0293
relative error from zero tallies = 0.0049

unnormed average tally per history = 1.39166E+05
estimated variance of the variance = 0.6723
relative error from nonzero scores = 0.0289

number of nonzero history tallies = 41221
history number of largest tally = 2652562
(largest tally)/(average tally) = 1.59309E+05

efficiency for the nonzero tallies = 0.0069
largest unnormalized history tally = 2.21704E+10
(largest tally)/(avg nonzero tally) = 1.09448E+03

(confidence interval shift)/mean = 0.0110

shifted confidence interval center = 2.74911E+01

if the largest history score sampled so far were to occur on the very next history, the tfc bin quantities would change as follows:

estimated quantities value at nps value at nps+1 value(nps+1)/value(nps)-1.

the estimated inverse power slope of the 200 largest tallies starting at 2.96750E+08 is 3.7719
the history score probability density function appears to have an unsampled region at the largest history scores: please examine.

abscissa		ordinate		tally plot of tally probability density function in tally fluctuation chart bin(d=decade,slope= 3.8)									
tally number	num den	log den:d	log den:d	d	d	d	d	d	d	d	d	d	d
1.58+05	7	3.58-11	-10.446	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2.00+05	4	1.62-11	-10.789	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2.51+05	31	1.00-10	-10.000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
3.16+05	193	4.95-10	-9.306	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
3.98+05	365	7.43-10	-9.129	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5.01+05	506	8.18-10	-9.087	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6.31+05	577	7.41-10	-9.130	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7.94+05	727	7.42-10	-9.130	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.00+06	957	7.76-10	-9.110	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.26+06	966	6.22-10	-9.206	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.58+06	1162	5.94-10	-9.226	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2.00+06	1064	4.32-10	-9.364	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2.51+06	1054	3.40-10	-9.468	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
3.16+06	1113	2.85-10	-9.545	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
3.98+06	1507	3.07-10	-9.513	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5.01+06	1950	3.15-10	-9.501	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6.31+06	2435	3.13-10	-9.505	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7.94+06	2650	2.70-10	-9.568	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.00+07	3014	2.44-10	-9.612	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.26+07	3524	2.27-10	-9.644	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.58+07	3778	1.93-10	-9.714	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2.00+07	2817	1.14-10	-9.942	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2.51+07	2741	8.84-11	-10.053	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
3.16+07	2583	6.62-11	-10.179	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
3.98+07	1833	3.73-11	-10.428	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5.01+07	1243	2.01-11	-10.697	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6.31+07	749	9.62-12	-11.017	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7.94+07	468	4.77-12	-11.321	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.00+08	248	2.01-12	-11.697	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.26+08	165	1.06-12	-11.974	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.58+08	183	9.36-13	-12.029	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2.00+08	169	6.86-13	-12.163	.....	.....	.....	.....						

7.94+08	23	2.35-14	-13.630	.....|.....|.....|	s	|	|	|	|
1.00+09	7	5.67-15	-14.246	.....|.....|.....|	s	|	|	|	|
1.26+09	8	5.15-15	-14.288	.....|.....|.....|	s	|	|	|	|
1.58+09	1	5.11-16	-15.291	.....|.....|.....|	s	|	|	|	|
2.00+09	1	4.06-16	-15.391	.....|.....|.....|	s	|	|	|	|
2.51+09	0	0.00+00	0.000	|	s	|	|	|	|
3.16+09	1	2.56-16	-15.591	.....|.....|.....|	s	|	|	|	|
3.98+09	0	0.00+00	0.000	|	s	|	|	|	|
5.01+09	0	0.00+00	0.000	|	s	|	|	|	|
6.31+09	0	0.00+00	0.000	|	s	|	|	|	|
7.94+09	0	0.00+00	0.000	s|	|	|	|	|	|
1.00+10	0	0.00+00	0.000	s	|	|	|	|	|
1.26+10	0	0.00+00	0.000	s	|	|	|	|	|
1.58+10	0	0.00+00	0.000	|	|	|	|	|	|
2.00+10	0	0.00+00	0.000	|	|	|	|	|	|
2.51+10	1	3.23-17	-16.491	*	|	|	|	|	|

total 41221 6.87-03 d-----d-----d-----d-----d-----d-----d-----d-----d-----
status of the statistical checks used to form confidence intervals for the mean for each tally bin

tally result of statistical checks for the ttc bin (the first check not passed is listed) and error magnitude check for all bins

42 missed 2 of 10 ttc bin checks: the variance of the variance exceeds the recommended value of 0.1
missed all bin error check: 81 tally bins had 9 bins with zeros and 15 bins with relative errors exceeding 0.10

the 10 statistical checks are only for the tally fluctuation chart bin and do not apply to other tally bins.

the tally bins with zeros may or may not be correct: compare the source, cutoffs, multipliers, et cetera with the tally bins.

warning. 1 of the 1 tally fluctuation chart bins did not pass all 10 statistical checks.
warning. 1 of the 1 tallies had bins with relative errors greater than recommended.
tally fluctuation charts

nps	mean	tally error	42 vov	slope	fom
512000	2.8053E+01	0.0424	0.0229	3.8	29
1024000	2.7129E+01	0.0303	0.0177	5.4	28
1536000	2.6694E+01	0.0248	0.0148	4.2	28
2048000	2.6582E+01	0.0211	0.0101	5.8	29
2560000	2.6498E+01	0.0199	0.0263	4.7	26
3072000	2.8027E+01	0.0532	0.8028	3.2	3.0E+00
3584000	2.7750E+01	0.0464	0.7770	3.6	3.4E+00
4096000	2.7448E+01	0.0413	0.7562	3.4	3.8E+00
4608000	2.7403E+01	0.0371	0.7320	3.5	4.2E+00
5120000	2.7199E+01	0.0338	0.7145	3.7	4.5E+00
5632000	2.7188E+01	0.0311	0.6839	3.7	4.9E+00
6000000	2.7193E+01	0.0293	0.6723	3.8	5.1E+00

.....
dump no. 17 on file runtpe nps = 6000000 coll = 31154094 ctm = 226.80 nrm = 352150444

5 warning messages so far.

run terminated when 6000000 particle histories were done.

computer time = 229.91 minutes

mcnp version 4a 10/01/93

02/01/97 15:13:04

probid = 02/01/97 11:23:09

ATTACHMENT V THERMAL ANALYSIS INPUT FILES

An estimation of the Heat Flux Values for Cases 4 through 7 is calculated as follows:

a. Heat Flux Value for Case 4

Internal heat source: $q = 100$ watts
Internal surface area A :

$$A = (2)[(0.3)(0.9) + (0.3)(0.5) + (0.5)(0.9)] = 1.74 \text{ m}^2$$

Heat flux q'' :

$$q'' = \frac{q}{A} = \frac{100}{1.74} = 57.4713 \text{ W/m}^2$$

b. Heat Flux Value for Cases 5 through 7

Internal heat source: $q = 400$ watts
Internal surface area: $A = 1.74 \text{ m}^2$

Heat flux q'' :

$$q'' = \frac{q}{A} = \frac{400}{1.74} = 229.885 \text{ W/m}^2$$

THERMAL ANALYSIS ANSYS INPUT FILES

The files within this attachment provide a complete listing of all of the inputs used to generate the ANSYS 5.2 thermal analysis described in Section 7.6.6. The graphical outputs of this analysis are contained in Attachment II. The file formats were developed from generic input templates and contain parameters that are used in each specific analysis.

/BATCH,LIST

```
*****
!
!                                     ANSYS INPUT
!
!  Filename:      pc das3d1
!  Input File:    pc das3d1.dat
!  Output File:   pc das3d1.out
!  Description:   3D Model for performance confirmation data
!                  acquisition system (pc das3d)
!                  WP location:      1.0 m above floor
!                  Drift inside diameter: 5.1 m
!                  WP spacing:      18.92 m
!                  WP diameter:     1.85 m
!                  WP length:       5.85 m
!                  Electronics box size: 1.0 m long
!                                      0.4 m wide
!                                      0.6 m high
!                                      0.05 m thick
!                  Insulating box size: 2.0 m long
!                                      0.44 m wide (Case 2,4,5,6 & 7)
!                                      0.52 m wide (Case 3)
!                                      1.0 m high
!                                      0.01 m thick (Case 2,4,5,6 & 7)
!                                      0.05 m thick (Case 3)
!                  Distance from waste
!                  package to box: 0.2 m
!                  Modeling time: 2 hours
!                  Model Identifier:
!                  Steel box w/o insulation: Case No. 1 (1)
!                  Steel box w/ insulation,
!                  w/o internal heat & cooling:
!                  insul. box thickness=0.01 m: Case No. 2 (2)
!                  Steel box w/ insulation,
!                  w/o internal heat & cooling,
!                  insul. box thickness=0.05 m: Case No. 3 (3)
!                  Steel box w/ insulation,
!                  w/ 100W of internal heat,
!                  w/o cooling: Case No. 4 (4)
!                  Steel box w/ insulation,
!                  w/ 400W of internal heat,
!                  w/o cooling: Case No. 5 (5)
!                  Steel box w/ insulation,
!                  w/ 400W of internal heat,
!                  w/ cooling, h=4.5W/m^2-K: Case No. 6 (6)
!                  Steel box w/ insulation,
!                  w/ 400W of internal heat,
!                  w/ cooling, h=12W/m^2-K: Case No. 7 (7)
!
!  Code Version:  ANSYS Revision 5.2
!  Created By:    Yiming Sun
!  Last Modified: 03/15/97
!
!*****
```

/COM,ANSYS MEDIA REV. 5.2

```
!
! /FILNAM,pc das3d1 ! Jobname to use for all subsequent files
! /TITLE,3D Model (PC DAS; Case 1: w/o Insulation)
! /UNITS,SI
! /SHOW
!
! /NOPR
! *ABB,SAVE_DB ,SAVE
```

```
*ABB,RESUM,DB,RESUME
*ABB,QUIT      ,Fnc_/EXIT
*ABB,SHFR      ,/SHOW,FILE,,8
*ABB,SHFV      ,/SHOW,FILE,,1
*ABB,X11C      ,/SHOW,X11C,,8
*ABB,X11       ,/SHOW,X11,,1
*ABB,REPLLOT   ,/REPLLOT
*ABB,K1        ,/FNUM,KP,1
*ABB,KO        ,/FNUM,KP,0
*ABB,POWRGRPH,Fnc_/GRAPHICS
*ABB,ANSYSWEB,Fnc_HomePage
/GO
!
/FDELE,EMAT,DELE
/FDELE,ESAV,DELE
/FDELE,EROT,DELE
/FDELE,DSUB,DELE
/FDELE,TRI,DELE
/FDELE,OSAV,DELE
/FDELE,PAGE,DELE
!
/PREP7
!
      Define element types
!
ET,1,SOLID70      !      8-node, 3-D thermal solid element
ET,2,SHELL57      !      Thermal shell element
R,1,1.0
ET,3,MATRIX50     !      Superelement for radiation
KEYOPT,3,1,1      !      Superelement behavior: radiation substructure
KEYOPT,3,6,0
!
      Define material properties
!
      Material number 1 (Drift wall - concrete)
MP,DENS,1,2323      !      Density (kg/m^3)
MP,KXX, 1,2.5       !      Thermal conductivity (W/m-K)
MP,C, 1,1005.0      !      Specific heat (J/kg-K)
MP,EMIS,1,0.9       !      Emissivity
!
      Material number 2 (Device box - stainless steel)
MP,DENS,2,7817      !      Density (kg/m^3)
MP,KXX, 2,16.3      !      Thermal conductivity (W/m-K)
MP,C, 2,460         !      Specific heat (J/kg-K)
MP,EMIS,2,0.8       !      Emissivity
!
      Material number 3 (Insulating box - fiber)
MP,DENS,3,240       !      Density (kg/m^3)
MP,KXX, 3,0.048     !      Thermal conductivity (W/m-K)
MP,C, 3,700         !      Specific heat (J/kg-K)
MP,EMIS,3,0.02      !      Emissivity
!
      Material number 4 (Waste package)
MP,DENS,4,8131      !      Density (kg/m^3)
MP,KXX, 4,41.709    !      Thermal conductivity (W/m-K)
MP,C, 4,487.901     !      Specific heat (J/kg-K)
MP,EMIS,4,0.8       !      Emissivity
!
      Material number 5 (Shell elements)
MP,EMIS,5,0.85      !      Emissivity
!
      Material number 6 (Superelement element)
MP,EMIS,6,0.85      !      Emissivity
!
      Parameters for model generation
!
ORIG=0.0
R1=2.55
R2=2.75
RW=0.925
Z1=9.46
Z2=6.535
Z3=8.96
Z4=9.01
XOW=0.0
YOW=-0.825
ZOW=0.0
OHD=0.3
OWD=0.2
IHD=0.25
IWD=0.15
XOD=-1.325
YOD=-0.825
ZOD=0.0
!
K,1, IWD,ORIG,Z1
K,2, OWD,ORIG,Z1
```

```
K.3, IWD, IHD,Z1
K.4, OWD, OHD,Z1
K.5, ORIG, IHD,Z1
K.6, ORIG, OHD,Z1
K.7, IWD,ORIG,Z4
K.8, OWD,ORIG,Z4
K.9, IWD, IHD,Z4
K.10, OWD, OHD,Z4
K.11,ORIG, IHD,Z4
K.12,ORIG, OHD,Z4
K.13, IWD,ORIG,Z3
K.14, OWD,ORIG,Z3
K.15, IWD, IHD,Z3
K.16, OWD, OHD,Z3
K.17,ORIG, IHD,Z3
K.18,ORIG, OHD,Z3
!
CYLIND,R1,R2,ORIG,Z1,0.90      !      Wall rock shell
CYLIND,RW,,Z2,Z1,,90          !      Waste package cylinder
!
V.1,2,4,3,7,8,10,9
V.3,4,6,5,9,10,12,11
V.7,8,10,9,13,14,16,15
V.9,10,12,11,15,16,18,17
BLOCK,ORIG,IWD,ORIG,IHD,Z3,Z4
!
VSYMM,Y,ALL,,,,,0,0
VSYMM,X,ALL,,,,,0,0
!
VGEN,,2,2,1,XOW,YOW,ZOW,,,1    !      Offset WP location
VGEN,,9,9,1,XOW,YOW,ZOW,,,1
VGEN,,16,16,1,XOW,YOW,ZOW,,,1
VGEN,,23,23,1,XOW,YOW,ZOW,,,1
!
VGEN,,3,7,1,XOD,YOD,ZOD,,,1    !      Offset device box
VGEN,,10,14,1,XOD,YOD,ZOD,,,1
VGEN,,17,21,1,XOD,YOD,ZOD,,,1
VGEN,,24,28,1,XOD,YOD,ZOD,,,1
!
VGLUE,ALL
/TRIAD,ROBOT
VPLOT
SAVE
!
!      Meshing
!
TYPE,1,                          !      Mesh the waste package
MAT,4,
ESYS,0,
ESHAPE,2,0
ESIZE,0.45,0,
VMESH,2,
VMESH,29,31,1
!
TYPE,1,                          !      Mesh the device box
MAT,2,
ESYS,0,
ESHAPE,2,0
ESIZE,0.05,0,
LSEL,S,LINE,,22
LSEL,A,LINE,,27
LSEL,A,LINE,,42,44,1
LSEL,A,LINE,,63
LSEL,A,LINE,,174,176,1
LSEL,A,LINE,,159
LSEL,A,LINE,,154
LSEL,A,LINE,,35
LSEL,A,LINE,,39
LSEL,A,LINE,,52
LSEL,A,LINE,,101
LSEL,A,LINE,,105
LSEL,A,LINE,,118
LSEL,A,LINE,,24
LSEL,A,LINE,,31
LSEL,A,LINE,,47
LSEL,A,LINE,,156
LSEL,A,LINE,,163
LSEL,A,LINE,,177
LSEL,A,LINE,,222
LSEL,A,LINE,,229
LSEL,A,LINE,,245
LSEL,A,LINE,,90
LSEL,A,LINE,,97
LSEL,A,LINE,,113
LSEL,A,LINE,,243
LSEL,A,LINE,,111
LSEL,A,LINE,,46
```

LSEL,A,LINE,,177
LSEL,A,LINE,,114
LSEL,A,LINE,,48
LSEL,A,LINE,,180
LSEL,A,LINE,,246
LESIZE,ALL,,3

LSEL,S,LINE,,36
LSEL,A,LINE,,102
LSEL,A,LINE,,287
LSEL,A,LINE,,304
LSEL,A,LINE,,41
LSEL,A,LINE,,107
LSEL,A,LINE,,290
LSEL,A,LINE,,306
LESIZE,ALL,,4

LSEL,S,LINE,,25
LSEL,A,LINE,,157
LSEL,A,LINE,,283
LSEL,A,LINE,,311
LSEL,A,LINE,,33
LSEL,A,LINE,,286
LSEL,A,LINE,,165
LSEL,A,LINE,,314
LESIZE,ALL,,4

LSEL,S,LINE,,32
LSEL,A,LINE,,164
LSEL,A,LINE,,98
LSEL,A,LINE,,230
LSEL,A,LINE,,30
LSEL,A,LINE,,161
LSEL,A,LINE,,95
LSEL,A,LINE,,227
LESIZE,ALL,,8

VMESH,3,6,1
VMESH,37
VMESH,11,13,2
VMESH,34,36,2
VMESH,42
VMESH,17,19,2
VMESH,35,38,3
VMESH,45
VMESH,40,41,1
VMESH,43,44,1
VMESH,46

! Mesh the drift wall

TYPE,1,
MAT,1,
ESYS,0,
ESIZE,0.5,0,
LSEL,S,LINE,,8
LSEL,A,LINE,,72
LSEL,A,LINE,,140
LSEL,A,LINE,,6
LSEL,A,LINE,,1
LSEL,A,LINE,,69
LSEL,A,LINE,,133
LSEL,A,LINE,,3
LESIZE,ALL,,2

VMESH,1
VMESH,33
VMESH,32
VMESH,39
ALLSEL

! Define shell elements

TYPE,2,
MAT,5,
REAL,1,
ESYS,0,
ASEL,S,AREA,,9
ASEL,A,AREA,,151
ASEL,A,AREA,,155
ASEL,A,AREA,,159
ASEL,A,AREA,,7
ASEL,A,AREA,,149
ASEL,A,AREA,,153
ASEL,A,AREA,,157

! Drift wall

ASEL,A,AREA,,4
ASEL,A,AREA,,163
ASEL,A,AREA,,167
ASEL,A,AREA,,189

! Device surfaces

```
ASEL,A,AREA,,24
ASEL,A,AREA,,169
ASEL,A,AREA,,176
ASEL,A,AREA,,19
ASEL,A,AREA,,28
ASEL,A,AREA,,56
ASEL,A,AREA,,65
ASEL,A,AREA,,88
ASEL,A,AREA,,98
ASEL,A,AREA,,201
ASEL,A,AREA,,204
ASEL,A,AREA,,173
ASEL,A,AREA,,183
ASEL,A,AREA,,191
ASEL,A,AREA,,194
!
ASEL,A,AREA,,181
ASEL,A,AREA,,31
ASEL,A,AREA,,27
ASEL,A,AREA,,199
ASEL,A,AREA,,177
ASEL,A,AREA,,68
ASEL,A,AREA,,101
ASEL,A,AREA,,184
ASEL,A,AREA,,209
ASEL,A,AREA,,211
ASEL,A,AREA,,205
ASEL,A,AREA,,195
!
NSLA,S,1
ESURF,,
PLOT
!
/AUX12
EMIS,2,0.8,
STEF,5.67e-8,
GEOM,0,0,
SPACE,
ESEL,S,TYPE,,2,2
NSLE,S
VTYPE,0,
MPRINT,0
WRITE,pcdas3d1
FINISH
!
/PREP7
TYPE,3,
MAT,6,
REAL,1,
ESYS,0,
SE,pcdas3d1
!
ESEL,S,TYPE,,2,2
EDELE,ALL
ALLSEL
!
/SOLU
ANTYPE,TRANS
NROPT,AUTO
TOFFST,273
TINTP,0.005, , ,0.5,0.5,0.2
!
OUTPR,NSOL,2,
OUTRES,NSOL,2,
!
VSEL,ALL
ASEL,ALL
LSEL,ALL
KSEL,ALL
ESEL,ALL
NSLE,ALL
IC,ALL,TEMP,26,
ALLSEL
SAVE
!
! Load step number 1
TIME,7200
AUTOTS,1
DELTIM,0.05,0.05,100,0.0
KBC,1
VSEL,S,VOLU,,1
VSEL,A,VOLU,,32
VSEL,A,VOLU,,33
VSEL,A,VOLU,,39
ESLV,S
NSLE,S
D,ALL,TEMP,200,
```

Generate superelement for thermal radiation calculation

Save radiation matrices

Solution phase
Transient analysis
Program chosen Newton-Raphson option
Specify the temperature offset: 273 K
Use defaults of transient integration parameters
Solution printout at every 2 substeps
Solution data written to database at every 2 substeps

Initial temperature at all nodes

Title: Performance Confirmation

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Data Acquisition System

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VSEL,S,VOLU,,2
VSEL,A,VOLU,,29
VSEL,A,VOLU,,30
VSEL,A,VOLU,,31

ESLV,S
NSLE,S
D,ALL,TEMP,200,

!
ALLSEL
LSWRITE,1.

!
ALLSEL
LSSOLVE,1,1,1,
FINISH

! Solve with 1 load steps

/BATCH,LIST

```
*****
#
#                               ANSYS INPUT
#
#  Filename:      pcdas3d2
#
#  Input File:    pcdas3d2.dat
#
#  Output File:   pcdas3d2.out
#
#  Description:   3D Model for performance confirmation data
#                  acquisition system (pcdas3d)
#                  WP location:      1.0 m above floor
#                  Drift inside diameter: 5.1 m
#                  WP spacing:       18.92 m
#                  WP diameter:      1.85 m
#                  WP length:        5.85 m
#                  Electronics box size:
#                      1.0 m long
#                      0.4 m wide
#                      0.6 m high
#                      0.05 m thick
#                  Insulating box size:
#                      2.0 m long
#                      0.44 m wide (Case 2,4,5,6 & 7)
#                      0.52 m wide (Case 3)
#                      1.0 m high
#                      0.01 m thick (Case 2,4,5,6 & 7)
#                      0.05 m thick (Case 3)
#                  Distance from waste
#                  package to box:    0.2 m
#                  Modeling time:     3 hours
#                  Model Identifier:
#                  Steel box w/o insulation:      Case No. 1 (1)
#                  Steel box w/ insulation,
#                  w/o internal heat & cooling:
#                  insul. box thickness=0.01 m:   Case No. 2 (2)
#                  Steel box w/ insulation,
#                  w/o internal heat & cooling,
#                  insul. box thickness=0.05 m:   Case No. 3 (3)
#                  Steel box w/ insulation,
#                  w/ 100W of internal heat,
#                  w/o cooling:                    Case No. 4 (4)
#                  Steel box w/ insulation,
#                  w/ 400W of internal heat,
#                  w/o cooling:                    Case No. 5 (5)
#                  Steel box w/ insulation,
#                  w/ 400W of internal heat,
#                  w/ cooling, h=4.5W/m^2-K:       Case No. 6 (6)
#                  Steel box w/ insulation,
#                  w/ 400W of internal heat,
#                  w/ cooling, h=12W/m^2-K:       Case No. 7 (7)
#
#  Code Version:  ANSYS Revision 5.2
#
#  Created By:    Yiming Sun
#
#  Last Modified: 03/15/97
#
*****
```

/COM,ANSYS MEDIA REV. 5.2

```
!
/FILNAM,pcdas3d2 ! Jobname to use for all subsequent files
/TITLE,3D Model (PC DAS; Case 2: w/ Insulation; w/o Internal Heat & Cooling)
/UNITS,SI
/SHOW
!
/NOPR
*ABB,SAVE_DB,SAVE
*ABB,RESUM_DB,RESUME
*ABB,QUIT,Fnc_/EXIT
*ABB,SHFR,./SHOW,FILE,,8
*ABB,SHFV,./SHOW,FILE,,1
*ABB,X11C,./SHOW,X11C,,8
*ABB,X11,./SHOW,X11,,1
*ABB,REPLOT,./REPLOT
*ABB,K1,./PNUM,KP,1
*ABB,K0,./PNUM,KP,0
*ABB,POWRGRPH,Fnc_/GRAPHICS
*ABB,ANSYSWEB,Fnc_HomePage
/GO
!
/FDELE,EMAT,DELE
/FDELE,ESAV,DELE
/FDELE,EROT,DELE
/FDELE,DSUB,DELE
```

```

/FDELE,TRI,DELE
/FDELE,OSAV,DELE
/FDELE,PAGE,DELE
!
/PREP7
!
!       Define element types
!
ET,1,SOLID70      !      8-node, 3-D thermal solid element
ET,2,SHELL57      !      Thermal shell element
R,1,1,0
ET,3,MATRIX50     !      Superelement for radiation
KEYOPT,3,1,1      !      Superelement behavior: radiation substructure
KEYOPT,3,6,0
!
!       Define material properties
!
!       Material number 1 (Drift wall - concrete)
MP,DENS,1,2323    !      Density (kg/m^3)
MP,KXX,1,2.5      !      Thermal conductivity (W/m-K)
MP,C,1,1005.0     !      Specific heat (J/kg-K)
MP,EMIS,1,0.9     !      Emissivity
!
!       Material number 2 (Device box - stainless steel)
MP,DENS,2,7817    !      Density (kg/m^3)
MP,KXX,2,16.3     !      Thermal conductivity (W/m-K)
MP,C,2,460        !      Specific heat (J/kg-K)
MP,EMIS,2,0.8     !      Emissivity
!
!       Material number 3 (Insulating box - fiber)
MP,DENS,3,240     !      Density (kg/m^3)
MP,KXX,3,0.048    !      Thermal conductivity (W/m-K)
MP,C,3,700        !      Specific heat (J/kg-K)
MP,EMIS,3,0.02    !      Emissivity
!
!       Material number 4 (Waste package)
MP,DENS,4,8131    !      Density (kg/m^3)
MP,KXX,4,41.709   !      Thermal conductivity (W/m-K)
MP,C,4,487.901    !      Specific heat (J/kg-K)
MP,EMIS,4,0.8     !      Emissivity
!
!       Material number 5 (Shell elements)
MP,EMIS,5,0.02    !      Emissivity
!
!       Material number 6 (Superelement element)
MP,EMIS,6,0.02    !      Emissivity
!
!       Parameters for model generation
!
ORIG=0.0
R1=2.55
R2=2.75
RW=0.925
Z1=9.46
Z2=6.535
Z3=8.96
Z4=9.01
Z5=8.46
Z6=8.47
XOW=0.0
YOW=-0.825
ZOW=0.0
OHD=0.3           !      Device box
OWD=0.2
IHD=0.25
IWD=0.15
XOD=-1.345
YOD=-0.825
ZOD=0.0
OHI=0.5           !      Insulating box
OWI=0.22
IHI=0.49
IWI=0.21
!
K,1,IWD,ORIG,Z1
K,2,OWD,ORIG,Z1
K,3,IWD,IHD,Z1
K,4,OWD,OHD,Z1
K,5,ORIG,IHD,Z1
K,6,ORIG,OHD,Z1
K,7,IWD,ORIG,Z4
K,8,OWD,ORIG,Z4
K,9,IWD,IHD,Z4
K,10,OWD,OHD,Z4
K,11,ORIG,IHD,Z4
K,12,ORIG,OHD,Z4
K,13,IWD,ORIG,Z3

```

```

K.14, OWD, ORIG, Z3
K.15, IWD, IHD, Z3
K.16, OWD, OHD, Z3
K.17, ORIG, IHD, Z3
K.18, ORIG, OHD, Z3
!
CYLIND, R1, R2, ORIG, Z1, 0, 90
CYLIND, RW, Z2, Z1, 90
!
V.1, 2, 4, 3, 7, 8, 10, 9
V.3, 4, 6, 5, 9, 10, 12, 11
V.7, 8, 10, 9, 13, 14, 16, 15
V.9, 10, 12, 11, 15, 16, 18, 17
BLOCK, ORIG, IWD, ORIG, IHD, Z3, Z4
!
VSMM, Y, ALL, 0, 0
VSMM, X, ALL, 0, 0
!
VGEN, 2, 2, 1, XOW, YOW, ZOW, 1
VGEN, 9, 9, 1, XOW, YOW, ZOW, 1
VGEN, 16, 16, 1, XOW, YOW, ZOW, 1
VGEN, 23, 23, 1, XOW, YOW, ZOW, 1
!
VGEN, 3, 7, 1, XOD, YOD, ZOD, 1
VGEN, 10, 14, 1, XOD, YOD, ZOD, 1
VGEN, 17, 21, 1, XOD, YOD, ZOD, 1
VGEN, 24, 28, 1, XOD, YOD, ZOD, 1
!
VGLUE, ALL
!
K.201, IWI, ORIG, Z1
K.202, OWI, ORIG, Z1
K.203, IWI, IHI, Z1
K.204, OWI, OHI, Z1
K.205, ORIG, IHI, Z1
K.206, ORIG, OHI, Z1
K.207, IWI, ORIG, Z6
K.208, OWI, ORIG, Z6
K.209, IWI, IHI, Z6
K.210, OWI, OHI, Z6
K.211, ORIG, IHI, Z6
K.212, ORIG, OHI, Z6
K.213, IWI, ORIG, Z5
K.214, OWI, ORIG, Z5
K.215, IWI, IHI, Z5
K.216, OWI, OHI, Z5
K.217, ORIG, IHI, Z5
K.218, ORIG, OHI, Z5
!
V.201, 202, 204, 203, 207, 208, 210, 209
V.203, 204, 206, 205, 209, 210, 212, 211
V.207, 208, 210, 209, 213, 214, 216, 215
V.209, 210, 212, 211, 215, 216, 218, 217
BLOCK, ORIG, IWI, ORIG, IHI, Z5, Z6
!
VSEL, S, VOLU, 7, 10, 1
VSEL, A, VOLU, 12
VSMM, Y, ALL, 0, 0
VSMM, X, ALL, 0, 0
!
VGEN, ALL, XOD, YOD, ZOD, 1
VGLUE, ALL
!
/TRIAD, RBOT
VPLT
ALLSEL
SAVE
!
! Meshing
!
TYPE, 1,
MAT, 4,
ESYS, 0,
ESHAPE, 2, 0,
ESIZE, 0.45, 0,
VMESH, 2,
VMESH, 29, 31, 1
!
TYPE, 1,
MAT, 2,
ESYS, 0,
ESHAPE, 2, 0,
ESIZE, 0.05, 0,
LSEL, S, LINE, 22
LSEL, A, LINE, 27
LSEL, A, LINE, 42, 44, 1
LSEL, A, LINE, 63

```

Wall rock shell
Waste package cylinder

Offset WP location

Offset device box

Insulating box

Offset insulating box

Mesh the waste package

Mesh the device box

LSEL,A,LINE,,174,176,1

LSEL,A,LINE,,159

LSEL,A,LINE,,154

LSEL,A,LINE,,35

LSEL,A,LINE,,39

LSEL,A,LINE,,52

LSEL,A,LINE,,101

LSEL,A,LINE,,105

LSEL,A,LINE,,118

LSEL,A,LINE,,24

LSEL,A,LINE,,31

LSEL,A,LINE,,47

LSEL,A,LINE,,156

LSEL,A,LINE,,163

LSEL,A,LINE,,177

LSEL,A,LINE,,222

LSEL,A,LINE,,229

LSEL,A,LINE,,245

LSEL,A,LINE,,90

LSEL,A,LINE,,97

LSEL,A,LINE,,113

LSEL,A,LINE,,243

LSEL,A,LINE,,111

LSEL,A,LINE,,46

LSEL,A,LINE,,177

LSEL,A,LINE,,114

LSEL,A,LINE,,48

LSEL,A,LINE,,180

LSEL,A,LINE,,246

LESIZE,ALL,,3

!

LSEL,S,LINE,,36

LSEL,A,LINE,,102

LSEL,A,LINE,,287

LSEL,A,LINE,,304

LSEL,A,LINE,,41

LSEL,A,LINE,,107

LSEL,A,LINE,,290

LSEL,A,LINE,,306

LESIZE,ALL,,4

!

LSEL,S,LINE,,25

LSEL,A,LINE,,157

LSEL,A,LINE,,283

LSEL,A,LINE,,311

LSEL,A,LINE,,33

LSEL,A,LINE,,286

LSEL,A,LINE,,165

LSEL,A,LINE,,314

LESIZE,ALL,,4

!

LSEL,S,LINE,,32

LSEL,A,LINE,,164

LSEL,A,LINE,,98

LSEL,A,LINE,,230

LSEL,A,LINE,,30

LSEL,A,LINE,,161

LSEL,A,LINE,,95

LSEL,A,LINE,,227

LESIZE,ALL,,8

!

VMESH,3,6,1

VMESH,37

VMESH,11,13,2

VMESH,34,36,2

VMESH,42

VMESH,17,19,2

VMESH,35,38,3

VMESH,45

VMESH,40,41,1

VMESH,43,44,1

VMESH,46

!

TYPE,1,

MAT,1,

ESYS,0,

ESIZE,0.5,0,

LSEL,S,LINE,,8

LSEL,A,LINE,,72

LSEL,A,LINE,,140

LSEL,A,LINE,,6

LSEL,A,LINE,,1

LSEL,A,LINE,,69

LSEL,A,LINE,,133

LSEL,A,LINE,,3

LESIZE,ALL,,2

VMESH,1

! Mesh the drift wall

```
VMESH,33
VMESH,32
VMESH,39
ALLSEL
!
TYPE,1,           !      Mesh the insulating box
MAT,3,
ESYS,0,
ESIZE,0.1,0,
VMESH,7,10,1
VMESH,15,21,3
VMESH,23
VMESH,49,60,1
ALLSEL
!
TYPE,2,           !      Define shell elements
MAT,5,
REAL,1,
ESYS,0,
ASEL,S,AREA,,9    !      WP
ASEL,A,AREA,,151
ASEL,A,AREA,,155
ASEL,A,AREA,,159
ASEL,A,AREA,,7
ASEL,A,AREA,,149
ASEL,A,AREA,,153
ASEL,A,AREA,,157
!
ASEL,A,AREA,,4     !      Drift wall
ASEL,A,AREA,,163
ASEL,A,AREA,,167
ASEL,A,AREA,,189
!
ASEL,A,AREA,,39    !      Insulating box outside surfaces
ASEL,A,AREA,,34
ASEL,A,AREA,,49
ASEL,A,AREA,,53
ASEL,A,AREA,,48
ASEL,A,AREA,,45
ASEL,A,AREA,,238
!
ASEL,A,AREA,,226
ASEL,A,AREA,,77
ASEL,A,AREA,,93
ASEL,A,AREA,,233
ASEL,A,AREA,,252
ASEL,A,AREA,,234
ASEL,A,AREA,,96
!
ASEL,A,AREA,,230
ASEL,A,AREA,,110
ASEL,A,AREA,,240
ASEL,A,AREA,,120
ASEL,A,AREA,,262
ASEL,A,AREA,,241
ASEL,A,AREA,,123
!
ASEL,A,AREA,,254
ASEL,A,AREA,,244
ASEL,A,AREA,,257
ASEL,A,AREA,,247
ASEL,A,AREA,,264
ASEL,A,AREA,,258
ASEL,A,AREA,,248
!
ASEL,A,AREA,,41    !      Insulating box inside surfaces
ASEL,A,AREA,,36
ASEL,A,AREA,,236
ASEL,A,AREA,,228
ASEL,A,AREA,,80
ASEL,A,AREA,,251
ASEL,A,AREA,,232
ASEL,A,AREA,,261
ASEL,A,AREA,,112
ASEL,A,AREA,,263
ASEL,A,AREA,,246
ASEL,A,AREA,,256
!
ASEL,A,AREA,,14    !      Device box outside surfaces
ASEL,A,AREA,,24
ASEL,A,AREA,,169
ASEL,A,AREA,,176
ASEL,A,AREA,,19
ASEL,A,AREA,,28
ASEL,A,AREA,,56
ASEL,A,AREA,,65
ASEL,A,AREA,,88
```

```

ASEL,A,AREA,,98
ASEL,A,AREA,,201
ASEL,A,AREA,,204
ASEL,A,AREA,,173
ASEL,A,AREA,,183
ASEL,A,AREA,,191
ASEL,A,AREA,,194
!
ASEL,A,AREA,,181
ASEL,A,AREA,,31
ASEL,A,AREA,,27
ASEL,A,AREA,,199
ASEL,A,AREA,,177
ASEL,A,AREA,,68
ASEL,A,AREA,,101
ASEL,A,AREA,,184
ASEL,A,AREA,,209
ASEL,A,AREA,,211
ASEL,A,AREA,,205
ASEL,A,AREA,,195
!
NSLA,S,1
ESURF,,
PLOT
!
/AUX12
EMIS,2,0.02,
STEP,5.67e-8,
GEOM,0,0,
SPACE,,
ESEL,S,TYPE,,2,2
NSLE,S
VTYPE,0,,
MPRINT,0
WRITE,pcdas3d2
SAVE
FINISH
!
/PREP7
TYPE,3,
MAT,6,,
REAL,1,
ESYS,0,
SE,pcdas3d2
!
ESEL,S,TYPE,,2,2
EDELE,ALL
ALLSEL
!
/SOLU
ANTYPE,TRANS
NROPT,AUTO
TOFFST,273
TINTP,0.005,,.05,0.5,0.2
!
OUTPR,NSOL,2,
OUTRES,NSOL,2,
!
VSEL,ALL
ASEL,ALL
LSEL,ALL
KSEL,ALL
ESEL,ALL
NSEL,ALL
IC,ALL,TEMP,26,
ALLSEL
SAVE
!
! Load step number 1
TIME,10800
AUTOTS,1
DELTIM,0.05,0.05,300,0,0
KBC,1
VSEL,S,VOLU,,1
VSEL,A,VOLU,,32
VSEL,A,VOLU,,33
VSEL,A,VOLU,,39
ESLV,S
NSLE,S
D,ALL,TEMP,200,
VSEL,S,VOLU,,2
VSEL,A,VOLU,,29
VSEL,A,VOLU,,30
VSEL,A,VOLU,,31
ESLV,S
NSLE,S
D,ALL,TEMP,200,

```

Generate superelement for thermal radiation calculation

Save radiation matrices

Solution phase
Transient analysis
Program chosen Newton-Raphson option
Specify the temperature offset: 273 K
Use defaults of transient integration parameters
Solution printout at every 2 substeps
Solution data written to database at every 2 substeps

Initial temperature at all nodes

Drift wall temperature

WP temperature

Title: Performance Confirmation
Data Acquisition System

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!
ALLSEL
LSWRITE,1.
!

ALLSEL
LSSOLVE,1,1,1,
FINISH

! Solve with 1 load steps

/BATCH,LIST

```
*****
!
!                                     ANSYS INPUT
!
!  Filename:      pcdas3d3
!  Input File:    pcdas3d3.dat
!  Output File:   pcdas3d3.out
!  Description:   3D Model for performance confirmation data
!                  acquisition system (pcdas3d)
!                  WP location:      1.0 m above floor
!                  Drift inside diameter: 5.1 m
!                  WP spacing:      18.92 m
!                  WP diameter:     1.85 m
!                  WP length:       5.85 m
!                  Electronics box size:
!                      1.0 m long
!                      0.4 m wide
!                      0.6 m high
!                      0.05 m thick
!                  Insulating box size:
!                      2.0 m long
!                      0.44 m wide (Case 2,4,5,6 & 7)
!                      0.52 m wide (Case 3)
!                      1.0 m high
!                      0.01 m thick (Case 2,4,5,6 & 7)
!                      0.05 m thick (Case 3)
!                  Distance from waste
!                  package to box: 0.2 m
!                  Modeling time: 6 hours
!                  Model Identifier:
!                  Steel box w/o insulation:      Case No. 1 (1)
!                  Steel box w/ insulation,
!                  w/o internal heat & cooling:
!                  insul. box thickness=0.01 m:   Case No. 2 (2)
!                  Steel box w/ insulation,
!                  w/o internal heat & cooling,
!                  insul. box thickness=0.05 m:   Case No. 3 (3)
!                  Steel box w/ insulation,
!                  w/ 100W of internal heat,
!                  w/o cooling:                     Case No. 4 (4)
!                  Steel box w/ insulation,
!                  w/ 400W of internal heat,
!                  w/o cooling:                     Case No. 5 (5)
!                  Steel box w/ insulation,
!                  w/ 400W of internal heat,
!                  w/ cooling, h=4.5W/m^2-K:        Case No. 6 (6)
!                  Steel box w/ insulation,
!                  w/ 400W of internal heat,
!                  w/ cooling, h=12W/m^2-K:         Case No. 7 (7)
!
!  Code Version:  ANSYS Revision 5.2
!  Created By:    Yiming Sun
!  Last Modified: 03/17/97
!
!*****
```

/COM.ANSYS MEDIA REV. 5.2

```
!
! /FILNAM,pcdas3d3 ! Jobname to use for all subsequent files
! /TITLE,3D Model (PC DAS; Case 3: w/ Insulation; w/o Internal Heat & Cooling)
! /UNITS,SI
! /SHOW
!
! /NOPR
! *ABB,SAVE_DB,SAVE
! *ABB,RESUM_DB,RESUME
! *ABB,QUIT,Fnc_/EXIT
! *ABB,SHFR,./SHOW,FILE,,,8
! *ABB,SHFV,./SHOW,FILE,,1
! *ABB,X11C,./SHOW,X11C,,,8
! *ABB,X11,./SHOW,X11,,1
! *ABB,REPLOT,./REPLOT
! *ABB,K1,./PNUM,KP,1
! *ABB,K0,./PNUM,KP,0
! *ABB,POWERGRPH,Fnc_/GRAPHICS
! *ABB,ANSYSWEB,Fnc_HomePage
! /GO
!
! /FDELE,EMAT,DELE
! /FDELE,ESAV,DELE
! /FDELE,EROT,DELE
! /FDELE,DSUB,DELE
```

/FDELE,TRI,DELE
/FDELE,OSAV,DELE
/FDELE,PAGE,DELE

/PREP7

Define element types

ET,1,SOLID70 ! 8-node, 3-D thermal solid element
ET,2,SHELL57 ! Thermal shell element
R,1,1.0
ET,3,MATRIX50 ! Superelement for radiation
KEYOPT,3,1,1 ! Superelement behavior: radiation substructure
KEYOPT,3,6,0

Define material properties

Material number 1 (Drift wall - concrete)
MP,DENS,1,2323 ! Density (kg/m^3)
MP,KXX,1,2.5 ! Thermal conductivity (W/m-K)
MP,C,1,1005.0 ! Specific heat (J/kg-K)
MP,EMIS,1,0.9 ! Emissivity
Material number 2 (Device box - stainless steel)
MP,DENS,2,7817 ! Density (kg/m^3)
MP,KXX,2,16.3 ! Thermal conductivity (W/m-K)
MP,C,2,460 ! Specific heat (J/kg-K)
MP,EMIS,2,0.8 ! Emissivity
Material number 3 (Insulating box - fiber)
MP,DENS,3,240 ! Density (kg/m^3)
MP,KXX,3,0.048 ! Thermal conductivity (W/m-K)
MP,C,3,700 ! Specific heat (J/kg-K)
MP,EMIS,3,0.02 ! Emissivity
Material number 4 (Waste package)
MP,DENS,4,8131 ! Density (kg/m^3)
MP,KXX,4,41.709 ! Thermal conductivity (W/m-K)
MP,C,4,487.901 ! Specific heat (J/kg-K)
MP,EMIS,4,0.8 ! Emissivity
Material number 5 (Shell elements)
MP,EMIS,5,0.02 ! Emissivity
Material number 6 (Superelement element)
MP,EMIS,6,0.02 ! Emissivity

Parameters for model generation

ORIG=0.0
R1=2.55
R2=2.75
RW=0.925
Z1=9.46
Z2=6.535
Z3=8.96
Z4=9.01
Z5=8.46
Z6=8.51
XOW=0.0
YOW=-0.825
ZOW=0.0
OHD=0.3 ! Device box
OWD=0.2
IKD=0.25
IWD=0.15
XOD=-1.385
YOD=-0.825
ZOD=0.0
OHI=0.5 ! Insulating box
OWI=0.26
IHI=0.45
IWI=0.21
K,1, IWD,ORIG,Z1
K,2, OWD,ORIG,Z1
K,3, IWD, IHD,Z1
K,4, OWD, OHD,Z1
K,5, ORIG, IHD,Z1
K,6, ORIG, OHD,Z1
K,7, IWD,ORIG,Z4
K,8, OWD,ORIG,Z4
K,9, IWD, IHD,Z4
K,10, OWD, OHD,Z4
K,11,ORIG, IHD,Z4
K,12,ORIG, OHD,Z4
K,13, IWD,ORIG,Z3

**Title: Performance Confirmation
Data Acquisition System**

**DI: BCAI00000-01717-0200-00002 REV 00
ATTACHMENT V Date: 3/18/97 Page: V-17 of V-31**

```

K,14, OWD,ORIG,Z3
K,15, IWD, IHD,Z3
K,16, OWD, OHD,Z3
K,17,ORIG, IHD,Z3
K,18,ORIG, OHD,Z3
!
CYLIND,R1,R2,ORIG,Z1,0,90
CYLIND,RW,,Z2,Z1,,90
!
V,1,2,4,3,7,8,10,9
V,3,4,6,5,9,10,12,11
V,7,8,10,9,13,14,16,15
V,9,10,12,11,15,16,18,17
BLOCK,ORIG,IWD,ORIG,IHD,Z3,Z4
!
VSYMM,Y,ALL,,,,0,0
VSYMM,X,ALL,,,,0,0
!
VGEN,,2,2,1,XOW,YOW,ZOW,,,1
VGEN,,9,9,1,XOW,YOW,ZOW,,,1
VGEN,,16,16,1,XOW,YOW,ZOW,,,1
VGEN,,23,23,1,XOW,YOW,ZOW,,,1
!
VGEN,,3,7,1,XOD,YOD,ZOD,,,1
VGEN,,10,14,1,XOD,YOD,ZOD,,,1
VGEN,,17,21,1,XOD,YOD,ZOD,,,1
VGEN,,24,28,1,XOD,YOD,ZOD,,,1
!
VGLUE,ALL
!
K,201, IWI,ORIG,Z1
K,202, OWI,ORIG,Z1
K,203, IWI, IHI,Z1
K,204, OWI, OHI,Z1
K,205,ORIG, IHI,Z1
K,206,ORIG, OHI,Z1
K,207, IWI,ORIG,Z6
K,208, OWI,ORIG,Z6
K,209, IWI, IHI,Z6
K,210, OWI, OHI,Z6
K,211,ORIG, IHI,Z6
K,212,ORIG, OHI,Z6
K,213, IWI,ORIG,Z5
K,214, OWI,ORIG,Z5
K,215, IWI, IHI,Z5
K,216, OWI, OHI,Z5
K,217,ORIG, IHI,Z5
K,218,ORIG, OHI,Z5
!
V,201,202,204,203,207,208,210,209
V,203,204,206,205,209,210,212,211
V,207,208,210,209,213,214,216,215
V,209,210,212,211,215,216,218,217
BLOCK,ORIG,IWI,ORIG,IHI,Z5,Z6
!
VSEL,S,VOLU,,7,10,1
VSEL,A,VOLU,,12
VSYMM,Y,ALL,,,,0,0
VSYMM,X,ALL,,,,0,0
!
VGEN,,ALL,,,XOD,YOD,ZOD,,,1
VGLUE,ALL
!
/TRIAD,REBOT
VPLLOT
ALLSEL
SAVE
!
! Meshing
!
TYPE,1,
MAT,4,
ESYS,0,
ESHAPE,2,0
ESIZE,0.45,0,
VMESH,2,
VMESH,29,31,1
!
TYPE,1,
MAT,2,
ESYS,0,
ESHAPE,2,0
ESIZE,0.05,0,
LSEL,S,LINE,,22
LSEL,A,LINE,,27
LSEL,A,LINE,,42,44,1
LSEL,A,LINE,,63

```

! Wall rock shell
! Waste package cylinder

! Offset WP location

! Offset device box

! Insulating box

! Offset insulating box

! Mesh the waste package

! Mesh the device box

LSEL,A,LINE,,174,176,1

LSEL,A,LINE,,159

LSEL,A,LINE,,154

LSEL,A,LINE,,35

LSEL,A,LINE,,39

LSEL,A,LINE,,52

LSEL,A,LINE,,101

LSEL,A,LINE,,105

LSEL,A,LINE,,118

LSEL,A,LINE,,24

LSEL,A,LINE,,31

LSEL,A,LINE,,47

LSEL,A,LINE,,156

LSEL,A,LINE,,163

LSEL,A,LINE,,177

LSEL,A,LINE,,222

LSEL,A,LINE,,229

LSEL,A,LINE,,245

LSEL,A,LINE,,90

LSEL,A,LINE,,97

LSEL,A,LINE,,113

LSEL,A,LINE,,243

LSEL,A,LINE,,111

LSEL,A,LINE,,46

LSEL,A,LINE,,177

LSEL,A,LINE,,114

LSEL,A,LINE,,48

LSEL,A,LINE,,180

LSEL,A,LINE,,246

LESIZE,ALL,,3

!

LSEL,S,LINE,,36

LSEL,A,LINE,,102

LSEL,A,LINE,,287

LSEL,A,LINE,,304

LSEL,A,LINE,,41

LSEL,A,LINE,,107

LSEL,A,LINE,,290

LSEL,A,LINE,,306

LESIZE,ALL,,4

!

LSEL,S,LINE,,25

LSEL,A,LINE,,157

LSEL,A,LINE,,283

LSEL,A,LINE,,311

LSEL,A,LINE,,33

LSEL,A,LINE,,286

LSEL,A,LINE,,165

LSEL,A,LINE,,314

LESIZE,ALL,,4

!

LSEL,S,LINE,,32

LSEL,A,LINE,,164

LSEL,A,LINE,,98

LSEL,A,LINE,,230

LSEL,A,LINE,,30

LSEL,A,LINE,,161

LSEL,A,LINE,,95

LSEL,A,LINE,,227

LESIZE,ALL,,8

!

VMESH,3,6,1

VMESH,37

VMESH,11,13,2

VMESH,34,36,2

VMESH,42

VMESH,17,19,2

VMESH,35,38,3

VMESH,45

VMESH,40,41,1

VMESH,43,44,1

VMESH,46

!

TYPE,1.

MAT,1.

ESYS,0.

LSEL,S,LINE,,196

LSEL,A,LINE,,55

LSEL,A,LINE,,141

LSEL,A,LINE,,70

LSEL,A,LINE,,76

LSEL,A,LINE,,201

LSEL,A,LINE,,147

LSEL,A,LINE,,60

LSEL,A,LINE,,93

LSEL,A,LINE,,182

LSEL,A,LINE,,82

! Mesh the drift wall

```
LSEL,A,LINE,,218
LSEL,A,LINE,,65
LSEL,A,LINE,,205
LSEL,A,LINE,,257
LSEL,A,LINE,,166
LESIZE,ALL,,3
ESIZE,0.5,0,
LSEL,S,LINE,,8
LSEL,A,LINE,,72
LSEL,A,LINE,,140
LSEL,A,LINE,,6
LSEL,A,LINE,,1
LSEL,A,LINE,,69
LSEL,A,LINE,,133
LSEL,A,LINE,,3
LESIZE,ALL,,2
VMESH,1
VMESH,33
VMESH,32
VMESH,39
ALLSEL
!
TYPE,1,
MAT,3,
ESYS,0,
ESIZE,0.1,0,
VMESH,7,10,1
VMESH,15,21,3
VMESH,23
VMESH,49,60,1
ALLSEL
!
TYPE,2,
MAT,5,
REAL,1,
ESYS,0,
ASEL,S,AREA,,9
ASEL,A,AREA,,151
ASEL,A,AREA,,155
ASEL,A,AREA,,159
ASEL,A,AREA,,7
ASEL,A,AREA,,149
ASEL,A,AREA,,153
ASEL,A,AREA,,157
!
ASEL,A,AREA,,4
ASEL,A,AREA,,163
ASEL,A,AREA,,167
ASEL,A,AREA,,189
!
ASEL,A,AREA,,39
ASEL,A,AREA,,34
ASEL,A,AREA,,49
ASEL,A,AREA,,53
ASEL,A,AREA,,48
ASEL,A,AREA,,45
ASEL,A,AREA,,238
!
ASEL,A,AREA,,226
ASEL,A,AREA,,77
ASEL,A,AREA,,93
ASEL,A,AREA,,233
ASEL,A,AREA,,252
ASEL,A,AREA,,234
ASEL,A,AREA,,96
!
ASEL,A,AREA,,230
ASEL,A,AREA,,110
ASEL,A,AREA,,240
ASEL,A,AREA,,120
ASEL,A,AREA,,262
ASEL,A,AREA,,241
ASEL,A,AREA,,123
!
ASEL,A,AREA,,254
ASEL,A,AREA,,244
ASEL,A,AREA,,257
ASEL,A,AREA,,247
ASEL,A,AREA,,264
ASEL,A,AREA,,258
ASEL,A,AREA,,248
!
ASEL,A,AREA,,41
ASEL,A,AREA,,36
ASEL,A,AREA,,236
ASEL,A,AREA,,228
ASEL,A,AREA,,80
```

! Mesh the insulating box

! Define shell elements

! WP

! Drift wall

! Insulating box outside surfaces

! Insulating box inside surfaces

```

ASEL,A,AREA,,251
ASEL,A,AREA,,232
ASEL,A,AREA,,261
ASEL,A,AREA,,112
ASEL,A,AREA,,263
ASEL,A,AREA,,246
ASEL,A,AREA,,256
!
ASEL,A,AREA,,14
ASEL,A,AREA,,24
ASEL,A,AREA,,169
ASEL,A,AREA,,176
ASEL,A,AREA,,19
ASEL,A,AREA,,28
ASEL,A,AREA,,56
ASEL,A,AREA,,65
ASEL,A,AREA,,88
ASEL,A,AREA,,98
ASEL,A,AREA,,201
ASEL,A,AREA,,204
ASEL,A,AREA,,173
ASEL,A,AREA,,183
ASEL,A,AREA,,191
ASEL,A,AREA,,194
!
ASEL,A,AREA,,181
ASEL,A,AREA,,31
ASEL,A,AREA,,27
ASEL,A,AREA,,199
ASEL,A,AREA,,177
ASEL,A,AREA,,68
ASEL,A,AREA,,101
ASEL,A,AREA,,184
ASEL,A,AREA,,209
ASEL,A,AREA,,211
ASEL,A,AREA,,205
ASEL,A,AREA,,195
!
NSLA,S,1
ESURF,,
PLOT
!
/AUX12
EMIS,2,0.02,
STEF,5.67e-8,
GEOM,0,0,
SPACE,
ESEL,S,TYPE,,2,2
NSLE,S
VTYPE,0,
MPRINT,0
WRITE,pcdas3d3
SAVE
FINISH
!
/REP7
TYPE,3,
MAT,6,
REAL,1,
ESYS,0,
SE,pcdas3d3
!
ESEL,S,TYPE,,2,2
EDELE,ALL
ALLSEL
!
/SOLU
ANTYPE,TRANS
NROPT,AUTO
TOFFST,273
TINTP,0.005,,.0.5,0.5,0.2
!
OUTPR,NSOL,2,
OUTRES,NSOL,2,
!
VSEL,ALL
ASEL,ALL
LSEL,ALL
KSEL,ALL
ESEL,ALL
NSEL,ALL
IC,ALL,TEMP,26,
ALLSEL
SAVE
!
Load step number 1
TIME,21600

```

Device box outside surfaces

Generate superelement for thermal radiation calculation

Save radiation matrices

Solution phase
Transient analysis
Program chosen Newton-Raphson option
Specify the temperature offset: 273 K
Use defaults of transient integration parameters
Solution printout at every 2 substeps
Solution data written to database at every 2 substeps

Initial temperature at all nodes

```
AUTOTS,1
DELTIM,0.05,0.05,500,0,0
KBC,1
VSEL,S,VOLU,,1           !      Drift wall temperature
VSEL,A,VOLU,,32
VSEL,A,VOLU,,33
VSEL,A,VOLU,,39
ESLV,S
NSLE,S
D,ALL,TEMP,200,
VSEL,S,VOLU,,2           !      WP temperature
VSEL,A,VOLU,,29
VSEL,A,VOLU,,30
VSEL,A,VOLU,,31
ESLV,S
NSLE,S
D,ALL,TEMP,200,
!
ALLSEL
LSWRITE,1,
!
ALLSEL
LSSOLVE,1,1,1,           !      Solve with 1 load steps
FINISH
```

/BATCH,LIST

```

*****
!
!                                ANSYS INPUT                                !
!
!  Filename:      pcdas3d4                                                !
!  Input File:    pcdas3d4.dat                                           !
!  Output File:   pcdas3d4.out                                           !
!  Description:   3D Model for performance confirmation data             !
!                  acquisition system (pcdas3d)                           !
!                  WP location:      1.0 m above floor                   !
!                  Drift inside diameter: 5.1 m                         !
!                  WP spacing:       18.92 m                             !
!                  WP diameter:      1.85 m                             !
!                  WP length:        5.85 m                             !
!                  Electronics box size: 1.0 m long                     !
!                                      0.4 m wide                       !
!                                      0.6 m high                       !
!                                      0.05 m thick                     !
!                  Insulating box size: 2.0 m long                     !
!                                      0.44 m wide (Case 2,4,5,6 & 7)    !
!                                      0.52 m wide (Case 3)              !
!                                      1.0 m high                       !
!                                      0.01 m thick (Case 2,4,5,6 & 7)   !
!                                      0.05 m thick (Case 3)              !
!                  Distance from waste package to box: 0.2 m           !
!                  Modeling time:    3 hours                             !
!                  Model Identifier:                                         !
!                  Steel box w/o insulation: Case No. 1 (1)             !
!                  Steel box w/ insulation, w/o internal heat & cooling:   !
!                  insul. box thickness=0.01 m: Case No. 2 (2)         !
!                  Steel box w/ insulation, w/o internal heat & cooling,   !
!                  insul. box thickness=0.05 m: Case No. 3 (3)         !
!                  Steel box w/ insulation, w/ 100W of internal heat,     !
!                  w/o cooling: Case No. 4 (4)                           !
!                  Steel box w/ insulation, w/ 400W of internal heat,     !
!                  w/o cooling: Case No. 5 (5)                           !
!                  Steel box w/ insulation, w/ 400W of internal heat,     !
!                  w/ cooling, h=4.5W/m^2-K: Case No. 6 (6)             !
!                  Steel box w/ insulation, w/ 400W of internal heat,     !
!                  w/ cooling, h=12W/m^2-K: Case No. 7 (7)             !
!
!  Code Version:  ANSYS Revision 5.2                                     !
!  Created By:    Yiming Sun                                             !
!  Last Modified: 03/15/97                                              !
!
*****

```

/COM,ANSYS MEDIA REV. 5.2

```

!
!  /FILNAM,pcdas3d4 ! Jobname to use for all subsequent files
!  RESUME,pcdas3d2.db,, ! Use the database file for Case 2
!  /TITLE,3D Model (PC DAS; Case 4: w/ Insulation;w/ 100W of Internal Heat;w/o Cooling)
!  /UNITS,SI
!  /SHOW
!
!  /NOPR
!  *ABB,SAVE_DB,SAVE
!  *ABB,RESUM_DB,RESUME
!  *ABB,QUIT,Fnc_/EXIT
!  *ABB,SHFR, /SHOW,FILE,,8
!  *ABB,SHFV, /SHOW,FILE,,1
!  *ABB,X11C, /SHOW,X11C,,8
!  *ABB,X11, /SHOW,X11,,1
!  *ABB,REPLOT, /REPLOT
!  *ABB,K1, /PNUM,KP,1
!  *ABB,K0, /PNUM,KP,0
!  *ABB,POWRGRPH,Fnc_/GRAPHICS
!  *ABB,ANSYSWEB,Fnc_HomePage
!  /GO
!
!  /FDELE,EMAT,DELE
!  /FDELE,ESAV,DELE
!  /FDELE,EROT,DELE

```



```

/FDELE,DSUB,DELE
/FDELE,TRI,DELE
/FDELE,OSAV,DELE
/FDELE,PAGE,DELE
!
/SOLU
ANTYPE,TRANS
NROPT,AUTO
TOFFST,273
TINTP,0.005, , .0.5,0.5,0.2
!
OUTPR,NSOL,2,
OUTRES,NSOL,2,
!
VSEL,ALL
ASEL,ALL
LSEL,ALL
KSEL,ALL
ESEL,ALL
NSSEL,ALL
IC,ALL,TEMP,26,
ALLSEL
SAVE
!
!
! Load step number 1
TIME,10800
AUTOTS,1
DELTIM,0.05,0.05,300,0,0
KBC,1
VSEL,S,VOLU,,1
VSEL,A,VOLU,,32
VSEL,A,VOLU,,33
VSEL,A,VOLU,,39
ESLV,S
NSLE,S
D,ALL,TEMP,200,
VSEL,S,VOLU,,2
VSEL,A,VOLU,,29
VSEL,A,VOLU,,30
VSEL,A,VOLU,,31
ESLV,S
NSLE,S
D,ALL,TEMP,200,
ASEL,S,AREA,,16
ASEL,A,AREA,,21
ASEL,A,AREA,,179
ASEL,A,AREA,,171
ASEL,A,AREA,,58
ASEL,A,AREA,,198
ASEL,A,AREA,,175
ASEL,A,AREA,,90
ASEL,A,AREA,,208
ASEL,A,AREA,,203
ASEL,A,AREA,,193
ASEL,A,AREA,,210
SFA,ALL,1,HFLUX,57.4713,
!
ALLSEL
LSWRITE,1,
!
ALLSEL
LSSOLVE,1,1,1,
FINISH

```

Solution phase
Transient analysis
Program chosen Newton-Raphson option
Specify the temperature offset: 273 C
Use defaults of transient integration parameters
Solution printout at every 2 substeps
Solution data written to database at every 2 substeps

Initial temperature at all nodes

Drift wall temperature

WP temperature

Internal heat source

Solve with 1 load steps

/BATCH,LIST

```

*****
                                ANSYS INPUT
Filename:      pcdas3d5
Input File:    pcdas3d5.dat
Output File:   pcdas3d5.out
Description:    3D Model for performance confirmation data
                  acquisition system (pcdas3d)
                  WP location:      1.0 m above floor
                  Drift inside diameter: 5.1 m
                  WP spacing:       18.92 m
                  WP diameter:      1.85 m
                  WP length:        5.85 m
                  Electronics box size: 1.0 m long
                                      0.4 m wide
                                      0.6 m high
                                      0.05 m thick
                  Insulating box size: 2.0 m long
                                      0.44 m wide (Case 2,4,5,6 & 7)
                                      0.52 m wide (Case 3)
                                      1.0 m high
                                      0.01 m thick (Case 2,4,5,6 & 7)
                                      0.05 m thick (Case 3)
                  Distance from waste
                  package to box:    0.2 m
                  Modeling time:     3 hours
                  Model Identifier:
                  Steel box w/o insulation: Case No. 1 (1)
                  Steel box w/ insulation,
                  w/o internal heat & cooling:
                  insul. box thickness=0.01 m: Case No. 2 (2)
                  Steel box w/ insulation,
                  w/o internal heat & cooling,
                  insul. box thickness=0.05 m: Case No. 3 (3)
                  Steel box w/ insulation,
                  w/ 100W of internal heat,
                  w/o cooling: Case No. 4 (4)
                  Steel box w/ insulation,
                  w/ 400W of internal heat,
                  w/o cooling: Case No. 5 (5)
                  Steel box w/ insulation,
                  w/ 400W of internal heat,
                  w/ cooling, h=4.5W/m^2-K: Case No. 6 (6)
                  Steel box w/ insulation,
                  w/ 400W of internal heat,
                  w/ cooling, h=12W/m^2-K: Case No. 7 (7)
Code Version:  ANSYS Revision 5.2
Created By:    Yiming Sun
Last Modified: 03/15/97
*****

```

/COM,ANSYS MEDIA REV. 5.2

```

/FILNAM,pcdas3d5 ! Jobname to use for all subsequent files
RESUME,pcdas3d2.db, ! Use the database file for Case 2
/TITLE,3D Model (PC DAS; Case 5: w/ Insulation;w/ 400W of Internal Heat;w/o Cooling)
/UNITS,SI
/SHOW
/NOPR
*ABB,SAVE_DB,SAVE
*ABB,RESUM_DB,RESUME
*ABB,QUIT,Fnc_/EXIT
*ABB,SHFR,./SHOW,FILE,,8
*ABB,SHFV,./SHOW,FILE,,1
*ABB,X11C,./SHOW,X11C,,8
*ABB,X11,./SHOW,X11,,1
*ABB,REPLOT,./REPLOT
*ABB,K1,./PNUM,KP,1
*ABB,K0,./PNUM,KP,0
*ABB,POWRGRPH,Fnc_/GRAPHICS
*ABB,ANSYSWEB,Fnc_HomePage
/GO
/FDELE,EMAT,DELE
/FDELE,ESAV,DELE
/FDELE,EROT,DELE

```

```

/FDELE,DSUB,DELE
/FDELE,TRI,DELE
/FDELE,OSAV,DELE
/FDELE,PAGE,DELE
!
/SOLU
ANTYPE,TRANS
NROPT,AUTO
TOFFST,273
TINTP,0.005,.,.0.5.0.5,0.2
!
OUTPR,NSOL,2,
OUTRES,NSOL,2,
!
VSEL,ALL
ASEL,ALL
LSEL,ALL
KSEL,ALL
ESEL,ALL
NSEL,ALL
IC,ALL,TEMP,26,
ALLSEL
SAVE
!
! Load step number 1
TIME,10800
AUTOTS,1
DELTIM,0.05,0.05,300.0,0
KBC,1
VSEL,S,VOLU,,1
VSEL,A,VOLU,,32
VSEL,A,VOLU,,33
VSEL,A,VOLU,,39
ESLV,S
NSLE,S
D,ALL,TEMP,200,
VSEL,S,VOLU,,2
VSEL,A,VOLU,,29
VSEL,A,VOLU,,30
VSEL,A,VOLU,,31
ESLV,S
NSLE,S
D,ALL,TEMP,200,
ASEL,S,AREA,,16
ASEL,A,AREA,,21
ASEL,A,AREA,,179
ASEL,A,AREA,,171
ASEL,A,AREA,,58
ASEL,A,AREA,,198
ASEL,A,AREA,,175
ASEL,A,AREA,,90
ASEL,A,AREA,,208
ASEL,A,AREA,,203
ASEL,A,AREA,,193
ASEL,A,AREA,,210
SFA,ALL,1,HFLUX,229.885,
!
ALLSEL
LSWRITE,1,
!
ALLSEL
LSSOLVE,1,1,1,
FINISH

```

Solution phase
 Transient analysis
 Program chosen Newton-Raphson option
 Specify the temperature offset: 273 C
 Use defaults of transient integration parameters
 Solution printout at every 2 substeps
 Solution data written to database at every 2 substeps

Initial temperature at all nodes

Drift wall temperature

WP temperature

Internal heat source

Solve with 1 load steps

/BATCH,LIST

```

*****
ANSYS INPUT
Filename:      pcdas3d6
Input File:    pcdas3d6.dat
Output File:   pcdas3d6.out
Description:    3D Model for performance confirmation data
                  acquisition system (pcdas3d)
                  WP location:      1.0 m above floor
                  Drift inside diameter: 5.1 m
                  WP spacing:      18.92 m
                  WP diameter:     1.85 m
                  WP length:       5.85 m
                  Electronics box size: 1.0 m long
                                      0.4 m wide
                                      0.6 m high
                                      0.05 m thick
                  Insulating box size: 2.0 m long
                                      0.44 m wide (Case 2,4,5,6 & 7)
                                      0.52 m wide (Case 3)
                                      1.0 m high
                                      0.01 m thick (Case 2,4,5,6 & 7)
                                      0.05 m thick (Case 3)
                  Distance from waste
                  package to box: 0.2 m
                  Modeling time: 10 hours
                  Model Identifier:
                  Steel box w/o insulation: Case No. 1 (1)
                  Steel box w/ insulation,
                  w/o internal heat & cooling:
                  insul. box thickness=0.01 m: Case No. 2 (2)
                  Steel box w/ insulation,
                  w/o internal heat & cooling,
                  insul. box thickness=0.05 m: Case No. 3 (3)
                  Steel box w/ insulation,
                  w/ 100W of internal heat,
                  w/o cooling: Case No. 4 (4)
                  Steel box w/ insulation,
                  w/ 400W of internal heat,
                  w/o cooling: Case No. 5 (5)
                  Steel box w/ insulation,
                  w/ 400W of internal heat,
                  w/ cooling, h=4.5W/m^2-K: Case No. 6 (6)
                  Steel box w/ insulation,
                  w/ 400W of internal heat,
                  w/ cooling, h=12W/m^2-K: Case No. 7 (7)
Code Version:  ANSYS Revision 5.2
Created By:     Yiming Sun
Last Modified:  03/15/97
*****

```

```

/COM,ANSYS MEDIA REV. 5.2
!
/FILNAM,pcdas3d6 ! Jobname to use for all subsequent files
RESUME,pcdas3d2.db, ! Use the database file for Case 2
/TITLE,3D Model (PC DAS; Case 6: w/ Insulation;w/ 400W of Internal Heat & Cooling)
/UNITS,SI
/SHOW
!
/NOPR
*ABB,SAVE_DB,SAVE
*ABB,RESUM_DB,RESUME
*ABB,QUIT, /Fnc_/EXIT
*ABB,SHFR, /SHOW,FILE,,8
*ABB,SHFV, /SHOW,FILE,,1
*ABB,X11C, /SHOW,X11C,,8
*ABB,X11, /SHOW,X11,,1
*ABB,REPLOT, /REPLOT
*ABB,K1, /PNUM,KP,1
*ABB,K0, /PNUM,KP,0
*ABB,POWRGRPH, /Fnc_/GRAPHICS
*ABB,ANSYSWEB, /Fnc_HomePage
/GO
!
/FDELE,EMAT,DELE
/FDELE,ESAV,DELE
/FDELE,EROT,DELE

```

```

/FDELE,DSUB,DELE
/FDELE,TRI,DELE
/FDELE,OSAV,DELE
/FDELE,PAGE,DELE
!
/SOLU
ANTYPE,TRANS
NROPT,AUTO
TOFFST,273
TINTP,0.005,,.0.5.0.5,0.2
!
OUTPR,NSOL,2,
OUTRES,NSOL,2,
!
VSEL,ALL
ASEL,ALL
LSEL,ALL
KSEL,ALL
ESEL,ALL
NSEL,ALL
IC,ALL,TEMP,26,
ALLSEL
SAVE
!
! Load step number 1
TIME,36000
AUTOTS,1
DELTIM,0.05,0.05,1000.0,0
KBC,1
VSEL,S,VOLU,,1
VSEL,A,VOLU,,32
VSEL,A,VOLU,,33
VSEL,A,VOLU,,39
ESLV,S
NSLE,S
D,ALL,TEMP,200,
VSEL,S,VOLU,,2
VSEL,A,VOLU,,29
VSEL,A,VOLU,,30
VSEL,A,VOLU,,31
ESLV,S
NSLE,S
D,ALL,TEMP,200,
ASEL,S,AREA,,16
ASEL,A,AREA,,21
ASEL,A,AREA,,179
ASEL,A,AREA,,171
ASEL,A,AREA,,58
ASEL,A,AREA,,198
ASEL,A,AREA,,175
ASEL,A,AREA,,90
ASEL,A,AREA,,208
ASEL,A,AREA,,203
ASEL,A,AREA,,193
ASEL,A,AREA,,210
SPA,ALL,1,HFLUX,229.885,
!
! Active cooling
ASEL,S,AREA,,41
ASEL,A,AREA,,36
ASEL,A,AREA,,236
ASEL,A,AREA,,228
ASEL,A,AREA,,80
ASEL,A,AREA,,251
ASEL,A,AREA,,232
ASEL,A,AREA,,261
ASEL,A,AREA,,112
ASEL,A,AREA,,263
ASEL,A,AREA,,246
ASEL,A,AREA,,256
!
ASEL,A,AREA,,14
ASEL,A,AREA,,24
ASEL,A,AREA,,169
ASEL,A,AREA,,176
ASEL,A,AREA,,19
ASEL,A,AREA,,28
ASEL,A,AREA,,56
ASEL,A,AREA,,65
ASEL,A,AREA,,88
ASEL,A,AREA,,98
ASEL,A,AREA,,201
ASEL,A,AREA,,204
ASEL,A,AREA,,173
ASEL,A,AREA,,183
ASEL,A,AREA,,191

```

Solution phase
Transient analysis
Program chosen Newton-Raphson option
Specify the temperature offset: 273 C
Use defaults of transient integration parameters
Solution printout at every 2 substeps
Solution data written to database at every 2 substeps

Initial temperature at all nodes

Drift wall temperature

WP temperature

Internal heat source

Insulating box inside surfaces

Device box outside surfaces

ASEL,A,AREA,,194

!

ASEL,A,AREA,,181

ASEL,A,AREA,,31

ASEL,A,AREA,,27

ASEL,A,AREA,,199

ASEL,A,AREA,,177

ASEL,A,AREA,,68

ASEL,A,AREA,,101

ASEL,A,AREA,,184

ASEL,A,AREA,,209

ASEL,A,AREA,,211

ASEL,A,AREA,,205

ASEL,A,AREA,,195

!

SFA,ALL,1,CONV,4.5,0.0

!

ALLSEL

LSWRITE,1,

!

ALLSEL

LSSOLVE,1,1,1,

FINISH

!

Solve with 1 load steps

/BATCH,LIST

```
*****
!
!                                ANSYS INPUT                                !
!
!      Filename:      pcdas3d7                                           !
!      Input File:    pcdas3d7.dat                                       !
!      Output File:   pcdas3d7.out                                       !
!      Description:    3D Model for performance confirmation data        !
!                      acquisition system (pcdas3d)                       !
!                      WP location:      1.0 m above floor                !
!                      Drift inside diameter: 5.1 m                      !
!                      WP spacing:       18.92 m                         !
!                      WP diameter:      1.85 m                         !
!                      WP length:        5.85 m                         !
!                      Electronics box size: 1.0 m long ,                !
!                                           0.4 m wide                  !
!                                           0.6 m high                  !
!                                           0.05 m thick                 !
!                      Insulating box size: 2.0 m long                  !
!                                           0.44 m wide (Case 2,4,5,6 & 7) !
!                                           0.52 m wide (Case 3)         !
!                                           1.0 m high                  !
!                                           0.01 m thick (Case 2,4,5,6 & 7) !
!                                           0.05 m thick (Case 3)         !
!
!                      Distance from waste package to box: 0.2 m        !
!                      Modeling time:    12 hours                       !
!                      Model Identifier:                                     !
!                      Steel box w/o insulation:      Case No. 1 (1)      !
!                      Steel box w/ insulation,       !
!                      w/o internal heat & cooling:    !
!                      insul. box thickness=0.01 m:   Case No. 2 (2)      !
!                      Steel box w/ insulation,       !
!                      w/o internal heat & cooling,    !
!                      insul. box thickness=0.05 m:   Case No. 3 (3)      !
!                      Steel box w/ insulation,       !
!                      w/ 100W of internal heat,      !
!                      w/o cooling:                    Case No. 4 (4)      !
!                      Steel box w/ insulation,       !
!                      w/ 400W of internal heat,      !
!                      w/o cooling:                    Case No. 5 (5)      !
!                      Steel box w/ insulation,       !
!                      w/ 400W of internal heat,      !
!                      w/ cooling, h=4.5W/m^2-K:       Case No. 6 (6)      !
!                      Steel box w/ insulation,       !
!                      w/ 400W of internal heat,      !
!                      w/ cooling, h=12W/m^2-K:       Case No. 7 (7)      !
!
!      Code Version:   ANSYS Revision 5.2                               !
!      Created By:     Yiming Sun                                         !
!      Last Modified:  03/15/97                                           !
!
!*****
```

/COM,ANSYS MEDIA REV. 5.2

```
!
!      /FILNAM,pcdas3d7 !      Jobname to use for all subsequent files
!      RESUME,pcdas3d2.db,, !      Use the database file for Case 2
!      /TITLE,3D Model (PC DAS; Case 7: w/ Insulation;w/ 400W of Internal Heat & Cooling)
!      /UNITS,SI
!      /SHOW
!
!      /NOPR
!      *ABB,SAVE_DB,SAVE
!      *ABB,RESUM_DB,RESUME
!      *ABB,QUIT,Fnc_/EXIT
!      *ABB,SHFR,./SHOW,FILE,,8
!      *ABB,SHFV,./SHOW,FILE,,1
!      *ABB,X11C,./SHOW,X11C,,8
!      *ABB,X11,./SHOW,X11,,1
!      *ABB,REPLOT,./REPLOT
!      *ABB,K1,./PNUM,KP,1
!      *ABB,K0,./PNUM,KP,0
!      *ABB,POWRGRPH,Fnc_/GRAPHICS
!      *ABB,ANSYSWEB,Fnc_HomePage
!      /GO
!
!      /FDELE,EMAT,DELE
!      /FDELE,ESAV,DELE
!      /FDELE,EROT,DELE
```

```

/FDELE,DSUB,DELE
/FDELE,TRI,DELE
/FDELE,OSAV,DELE
/FDELE,PAGE,DELE
!
/SOLU
ANTYPE,TRANS          ! Solution phase
NROPT,AUTO             ! Transient analysis
TOFFST,273             ! Programchosen Newton-Raphson option
TINTP,0.005,.,.0.5,0.5,0.2 ! Specify the temperature offset: 273 C
! Use defaults of transient integration
! parameters
OUTPR,NSOL,2           ! Solution printout at every 2 substeps
OUTRES,NSOL,2          ! Solution data written to database
! at every 2 substeps
VSEL,ALL
ASEL,ALL
LSEL,ALL
KSEL,ALL
ESEL,ALL
NSEL,ALL
IC,ALL,TEMP,26.        ! Initial temperature at all nodes
ALLSEL
SAVE
!
! Load step number 1
TIME,43200
AUTOTS,1
DELTIM,0.05,0.05,1000.0,0
KBC,1
VSEL,S,VOLU,,1         ! Drift wall temperature
VSEL,A,VOLU,,32
VSEL,A,VOLU,,33
VSEL,A,VOLU,,39
ESLV,S
NSLE,S
D,ALL,TEMP,200.
VSEL,S,VOLU,,2         ! WP temperature
VSEL,A,VOLU,,29
VSEL,A,VOLU,,30
VSEL,A,VOLU,,31
ESLV,S
NSLE,S
D,ALL,TEMP,200.
ASEL,S,AREA,,16        ! Internal heat source
ASEL,A,AREA,,21
ASEL,A,AREA,,179
ASEL,A,AREA,,171
ASEL,A,AREA,,58
ASEL,A,AREA,,198
ASEL,A,AREA,,175
ASEL,A,AREA,,90
ASEL,A,AREA,,208
ASEL,A,AREA,,203
ASEL,A,AREA,,193
ASEL,A,AREA,,210
SFA,ALL,1,HFLUX,229.885,
!
! Active cooling
ASEL,S,AREA,,41        ! Insulating box inside surfaces
ASEL,A,AREA,,36
ASEL,A,AREA,,236
ASEL,A,AREA,,228
ASEL,A,AREA,,80
ASEL,A,AREA,,251
ASEL,A,AREA,,232
ASEL,A,AREA,,261
ASEL,A,AREA,,112
ASEL,A,AREA,,263
ASEL,A,AREA,,246
ASEL,A,AREA,,256
!
ASEL,A,AREA,,14        ! Device box outside surfaces
ASEL,A,AREA,,24
ASEL,A,AREA,,169
ASEL,A,AREA,,176
ASEL,A,AREA,,19
ASEL,A,AREA,,28
ASEL,A,AREA,,56
ASEL,A,AREA,,65
ASEL,A,AREA,,88
ASEL,A,AREA,,98
ASEL,A,AREA,,201
ASEL,A,AREA,,204
ASEL,A,AREA,,173
ASEL,A,AREA,,183
ASEL,A,AREA,,191

```


ASEL,A,AREA,,194
!
ASEL,A,AREA,,181
ASEL,A,AREA,,31
ASEL,A,AREA,,27
ASEL,A,AREA,,199
ASEL,A,AREA,,177
ASEL,A,AREA,,68
ASEL,A,AREA,,101
ASEL,A,AREA,,184
ASEL,A,AREA,,209
ASEL,A,AREA,,211
ASEL,A,AREA,,205
ASEL,A,AREA,,195
!
SFA,ALL,1,CONV,12.0,0.0
!
ALLSEL
LSWRITE,1,
!
ALLSEL
LSSOLVE,1,1,1,
FINISH

Solve with 1 load steps