TVA

Tennessee Valley Authority, Post Office Box 2000, Spring City, Tennessee 37381-2000

April 6, 2011

10 CFR 50.4(b)(6)
10 CFR 50.34(b)

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D.C. 20555-0001

Watts Bar Nuclear Plant, Unit 2
NRC Docket No. 50-391

Subject: **Watts Bar Nuclear Plant (WBN) Unit 2 – Safety Evaluation Report Supplement 22 (SSER22) - Response to NRC Required Action Items**

Appendix HH of NUREG-0847, Supplement 22, "Safety Evaluation Report Related to the Operation of Watts Bar Nuclear Plant, Unit 2," contains 51 "required action items associated of all open items, confirmatory issues, and proposed license conditions that the staff has identified."

Enclosure 1 contains the required actions and responses to 21 of these action items.

Enclosure 2 lists the 10 action items for which TVA will provide responses at a later date.

Enclosure 3 lists the 20 action items which require NRC inspection/review. TVA will provide a closure package for review as required.

Enclosure 4 provides the list of commitments made in this letter. If you have any questions, please contact Bill Crouch at (423) 365-2004.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 6th day of April, 2011.

Respectfully,

David Stinson
Watts Bar Unit 2 Vice President

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NRR

Enclosures:

1. Response to Action Items From Appendix HH of NUREG-0847, Supplement 22
2. Action Items From Appendix HH of NUREG-0847, Supplement 22 to Be Answered Later
3. Action Items From Appendix HH of NUREG-0847, Supplement 22 For NRC Inspection/Review
4. List of Regulatory Commitments

Attachments:

1. Response to TVA for Core Loading Information and End of Cycle Assembly Burnup Data for Watts Bar Unit 2 Cycle 1
2. A Review of Electronic Components in a Radiation Environment of ≤ $5x10^4$ RADS
3. Electrical Transient Analysis Program (ETAP) Voltage Recovery Plots

cc (Enclosures):

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ENCLOSURE 1

Response to Action Items From Appendix HH of NUREG-0847, Supplement 22

Tennessee Valley Authority - Watts Bar Nuclear Plant - Unit 2, Docket No. 50-391

The item numbers used below correspond to item numbers in SSER 22, Appendix HH.

3. *Confirm TVA submitted update to FSAR section 8.3.1.4.1. (NRC safety evaluation dated August 31, 2009, ADAMS Accession No. ML092151155)*

   Response: In Amendment 95 of the Unit 2 FSAR, the third sentence of the third paragraph of 8.3.1.4.1 reads "Any conduit exceeding 40% cable fill will be evaluated and justified by engineering."

   Amendment 95 of the Unit 2 FSAR was submitted to the NRC via TVA letter dated November 24, 2009, "Watts Bar Nuclear Plant (WBN) – Unit 2 – Final Safety Analysis Report (FSAR), Amendment 95," ADAMS Accession number ML093370275).

5. *Verify timely submittal of pre-startup core map and perform technical review. (TVA letter dated September 7, 2007, ADAMS Accession No. ML072570676)*

   Response: Attachment 1 provides the requested core map.

6. *Verify implementation of TSTF-449. (TVA letter dated September 7, 2007, ADAMS Accession No. ML072570676)*

   Response: Amendment 65 to the Unit 1 TS revised the existing steam generator tube surveillance program and was modeled after TSTF-449, Rev. 4. The NRC approved Amendment 65 via letter dated November 3, 2006, "Watts Bar Nuclear Plant, Unit 1 - Issuance of Amendment Regarding Steam Generator Tube Integrity (TS-05-10) (TAC No. MC9271)." Revision 82 made the associated changes to the Unit 1 TS Bases.

   Developmental Revision A to the Unit 2 TS and TS Bases made the equivalent changes to the Unit 2 TS / TS Bases. Affected TS sections include the following: LEAKAGE definition in 1.1, LCO 3.4.13 (*RCS Operational LEAKAGE*), LCO 3.4.17 (*SG Tube Integrity*), 5.7.2.12 (*Steam Generator (SG) Program*), and 5.9.9 (*Steam Generator Tube Inspection Report).*

   Developmental Revision A of the Unit 2 TS was submitted to the NRC via letter dated March 4, 2009, "Watts Bar Nuclear Plant (WBN) Unit 2 - Operating License Application Update," (ADAMS Accession number ML090700378).

8. *Verify rod control system operability during power ascension. TVA should provide a pre-startup map to the NRC staff indicating the rodded fuel assemblies and a projected end of cycle burnup of each rodded assembly for the initial fuel cycle 6-months prior to fuel load. (NRC safety evaluation dated May 3, 2010, ADAMS Accession No. ML101200035)*

Response: Attachment 1 provides the requested pre-startup map indicating the rodded fuel assemblies and the projected end of cycle burnup of each rodded assembly for the initial fuel cycle.

14. *TVA stated that the Unit 2 PTLR is included in the Unit 2 System Description for the Reactor Coolant System (WBN2-68-4001), which will be revised to reflect required revisions to the PTLR by September 17, 2010. (Section 5.3.1)*

Response: Revision 1 (effective August 12, 2010) to the Unit 2 System Description for the Reactor Coolant System (WBN2-68-4001) was revised to reflect the required revisions to the Pressure and Test Limits Report (PTLR).

15. *TVA should confirm to the NRC staff the completion of Primary Stress Corrosion Cracking (PWSCC) mitigation activities on the Alloy 600 dissimilar metal butt welds (DMBWs) in the primary loop piping. (Section 3.6.3)*

Response: Unit 2 has completed the Mechanical Stress Improvement Process (MSIP®). Amendment 103 to the Unit 2 FSAR added five new paragraphs to the end of Section 5.5.3.3.1 (*Material Corrosion/Erosion Evaluation*) to describe this process.

Amendment 103 was submitted via TVA to NRC letter dated March 15, 2011, "Watts Bar Nuclear Plant (WBN) – Unit 2 – Final Safety Analysis Report (FSAR), Amendment 103."

18. *Based on the extensive layup period of equipment within WBN Unit 2, the NRC staff must review, prior to fuel load, the assumptions used by TVA to re-establish a baseline for the qualified life of equipment. The purpose of the staff's review is to ensure that TVA has addressed the effects of environmental conditions on equipment during the layup period. (Section 3.11.2.2)*

Response: This item was addressed in the response to ***RAI 3.11 - EQ - 1.*** in TVA to NRC letter dated December 17, 2010, "Watts Bar Nuclear Plant (WBN) Unit 2 – Safety Evaluation Report Supplement 22 (SSER22) – Response to Requests for Additional Information" (ADAMS Accession No. ML103540560).

20. *Resolve whether or not routine maintenance activities should result in increasing the EQ of the 6.9 kV motors to Category I status in accordance with 10 CFR 50.49. (Section 3.11.2.2.1).*

Response: The refurbishment of the 6.9 kV motors for Unit 2 involved routine maintenance activities. These maintenance activities did not modify or repair the motor insulation system originally supplied by Westinghouse. However, review of the original qualification report indicates that the testing performed meets the requirements for a Category I qualification. Motors which only require routine maintenance will have their binders revised and will be re-classified as Category I.

In one case (Containment Spray Pump Motor), the maintenance activities determined the need to rewind the motor. The rewound motor insulation system is qualified in accordance with the EPRI motor rewind program which meets Category I criteria.

22. *TVA must clarify its use of the term "equivalent" (e.g., identical, similar) regarding the replacement terminal blocks to the NRC staff. If the blocks are similar, then a similarity analysis should be completed and presented to the NRC for review. (Section 3.11.2.2.1)*

Response: This item was addressed in the response to ***RAI 3.11 - EQ - 3.b.*** in TVA to NRC letter dated December 17, 2010, "Watts Bar Nuclear Plant (WBN) Unit 2 – Safety Evaluation Report Supplement 22 (SSER22) – Response to Requests for Additional Information" (ADAMS Accession No. ML103540560). The response stated, "For EQ applications, the replacement terminal blocks will be new GE CR151B terminal blocks certified to test reports that document qualification to NUREG-0588, Category I criteria."

TVA discussed this issue with the NRC during the ACRS meeting on February 24, 2011. The NRC staff accepted TVA's explanation of the term "equivalent" as provided above. Therefore, TVA considers this item to be closed.

23. *Resolve whether or not TVA's reasoning for not upgrading the MSIV solenoid valves to Category I is a sound reason to the contrary, as specified in 10 CFR 50.49(l). (Section 3.11.2.2.1)*

Response: TVA will qualify the MSIV solenoids to the Category I criteria.

24. *The NRC staff requires supporting documentation from TVA to justify its establishment of a mild environment threshold for total integrated dose of less than $1x10^3$ rads for electronic components such as semiconductors or electronic components containing organic material. (Section 3.11.2.2.1)*

Response: Calculation "A Review of Electronic Components in a Radiation Environment of $\leq 5x10^4$ RADS" is provided as Attachment 2.

26. *For the scenario with an accident in one unit and concurrent shutdown of the second unit without offsite power, TVA stated that Unit 2 pre-operational testing will validate the diesel response to sequencing of loads on the Unit 2 emergency diesel generators (EDGs). The NRC staff will evaluate the status of this issue and will update the status of the EDG load response in a future SSER. (Section 8.1)*

Response: There are four diesel generators (DGs) which supply onsite power to both Units 1 and 2 at Watts Bar Nuclear Plant. Each DG is dedicated to supply power to shutdown boards as follows:

- DG 1A-A feeds power into Unit 1, 6.9 kV shutdown board 1A-A
- DG 2A-A feeds power into Unit 2, 6.9 kV shutdown board 2A-A
- DG 1B-B feeds power into Unit 1, 6.9 kV shutdown board 1B-B
- DG 2B-B feeds power into Unit 2, 6.9 kV shutdown board 2B-B

Redundant trains of ESF loads for each unit are powered from each shutdown board. If offsite power is lost (LOOP), one train in each unit is capable of powering the loads required to mitigate the consequences of an accident or safely shut down the unit.

The following loading tables provide the blackout loading plus the common accident loads (load rejection, with an accident on the opposite unit and a loss of offsite power) for the safe shutdown of the non-accident unit. As discussed previously, these loadings are bounded by the accident loading.

Maximum Steady-State Running Load, 0 hrs to 2 hrs*

	1A-A	1B-B	2A-A	2B-B	Short-Time Rating	Minimum Margin (%)
Kw	3,540.71	3,492.81	3,593.87	3,702.44	4,840	23.5
Time (sec)	1,810	1,810	1,810	1,810		
KVA	3,952.32	4,182.61	3,979.04	4,123.56	6,050	30.8
Time (sec)	1,810	1,810	1,810	1,810		

Maximum Steady-State Running Load, 2 hrs to End**

	1A-A	1B-B	2A-A	2B-B	Continuous Rating	Minimum Margin (%)
Kw	3,540.71	3,492.81	3,593.87	3,702.44	4,400	15.8
Time (sec)	7,200	7,200	7,200	7,200		
KVA	3,952.32	4,182.61	3,979.04	4,123.56	5,500	23.9
Time (sec)	7,200	7,200	7,200	7,200		

Maximum Starting + Running (Transient) Loading, 0 to 180 sec

	1A-A	1B-B	2A-A	2B-B	Cold Engine Capability	Minimum Margin (%)
Kw	3,508.32	3,320.81	3,396.14	3,806.81	4,785	20.4
Time (sec)	90	90	90	90		

Maximum Starting + Running (Transient) Loading, 180 sec to End

	1A-A	1B-B	2A-A	2B-B	Hot Engine Capability	Minimum Margin (%)
Kw	3,806.30	3,948.00	3,994.52	3,997.23	5,073	21.2
Time (sec)	360	360	360	360		

Maximum Step Load Increase (Excitation), 0 sec to End

	1A-A	1B-B	2A-A	2B-B	Generator Step Load Capability	Minimum Margin (%)
Kw	3,645.01	3,728.75	3,722.30	3,725.01	8,000	53.4
Time (sec)	20	20	20	20		

* Automatic load sequencing only

** Includes operator actions (load additions)

27. *TVA should provide a summary of margin studies based on scenarios described in Section 8.1 for CSSTs A, B, C, and D. (Section 8.2.2)*

Response: TVA to NRC letter dated December 6, 2010, "Watts Bar Nuclear Plant (WBN) Unit 2 – Safety Evaluation Report Supplement 22 (SSER22) – Response to Requests for Additional Information," (ADAMS accession number ML103420569) included the response to ***RAI 8.2.2 - 1***. That response stated, "The loading for a dual unit trip (item a) is slightly less than the loading with one unit in accident and a spurious accident signal in the other unit. Therefore, a separate load flow was not performed."

A separate load flow was performed for a dual unit shutdown resulting from an abnormal operational occurrence with and without offsite power. The resulting loading on CSSTs is provided in the following table:

	STEADY STATE LOADING			**RATING**
	MW	**MVAR**	**MVA**	**MVA**
CSST C - X	10.75	4.68	11.72	24/32/40
CSST C - Y	11.02	4.96	12.08	24/32/40
CSST C - P	21.80	10.69	24.28	33/44/55

(The above loading on CSST C is with both ESF trains of both units powered from this transformer; CSST D is out of service)

CSST D - X	10.75	4.69	11.73	24/32/40
CSST D - Y	11.02	4.96	12.08	24/32/40
CSST D - P	21.80	10.70	24.28	33/44/55

(The above loading on CSST D is with both ESF trains of both units powered from this transformer; CSST C is out of service)

CSST A - X	21.86	9.28	23.75	36/48/60*
CSST A - Y	29.89	17.72	34.75	36/48/60*
CSST A - P	52.04	33.35	61.81	57/76/95*

(The above loading on CSST A is with one ESF train of each unit transferred to this transformer. CSST D is out of service; CSSTs C, A, and B are available.)

CSST B - X	21.86	9.28	23.75	36/48/60*
CSST B - Y	28.14	16.66	32.70	36/48/60*
CSST B - P	50.29	31.82	59.51	57/76/95*

(The above loading on CSST B is with one ESF train of each unit transferred to this transformer. CSST C is out of service; CSSTs D, A, and B are available.)

* The second FA rating for CSSTs A and B is "FUTURE."

The worst case margin for CSSTs C and D is 70% (X, Y winding) and 55% for primary winding. The worst case margin for CSSTs A and B is 27% (X, Y winding) and 18% for primary winding.

This additional analysis will be included in the next revision of AC Auxiliary Power System Analysis Calculation EDQ00099920070002.

28. *TVA should provide to the NRC staff a detailed discussion showing that the load tap changer is able to maintain the 6.9 kV bus voltage control band given the normal and post-contingency transmission operating voltage band, bounding voltage drop on the grid, and plant conditions. (Section 8.2.2)*

Response: For CSSTs C and D, the load tap changer (LTC) is set to regulate 6.9kV shutdown board voltage at 7,071V (102.5%). For CSSTs A and B, the LTC is set to regulate the voltage at the 6.9kV start buses (which can power the 6.9kV shutdown boards through the 6.9kV unit boards) at 7,071V (102.5%). The upper and lower setpoints of the dead bands are 7,132V (103.4%) and 7,010V (101.6%), respectively. The dead band considered is ±82.2V equivalent to the operating tolerances identified for these setpoints. The LTCs have the following parameters:

CSST C and D:	Taps ±10%, Tap Step 1.25%, Total No of Taps 17, Initial Time Delay 2 seconds, Operating Time 1 second. Taps are provided on each secondary winding.
CSST A and B:	Taps ±16.8%, Tap Step 1.05%, Total No of Taps 33, Initial Time Delay 1 second, Operating Time 2 seconds. Taps are provided on the primary winding.

The analysis evaluates the 6.9-kV shutdown board minimum voltage requirements considering a maximum (bounding) grid voltage drop of 9 kV and a minimum grid voltage of 153kV and all plant conditions. Although the calculated shutdown board voltage falls below the degraded voltage relay dropout setpoint due to block start of ESF motors, it recovers above the degraded voltage relay reset setpoint in ≤5 seconds. The minimum time for the degraded voltage relays to isolate the offsite power from the 6.9kV Shutdown Boards is 8.5 seconds.

Attachment 3 provides the Electrical Transient Analysis Program (ETAP) voltage recovery plots following a DBE on one unit while the other unit is in simultaneous orderly shutdown. These plots pictorially depict the LTC function at different times following a DBE.

During normal operation and post-accident with bounding grid voltage (153kV), the voltage on the 6.9kV shutdown boards is maintained within the LTC control band. As shown in the ETAP plots, the voltage on the shutdown boards falls below the degraded voltage relay setpoint due to block start of ESF motors but recovers to a value above the degraded voltage relay reset value before the degraded voltage relay timer times out so as not to isolate the shutdown boards from the offsite power. The source is therefore in compliance with GDC 17 and is able to supply offsite power to 1E loads with an accident in one unit, safe shutdown of the opposite unit, and the worst case single failure.

31. *TVA should evaluate the re-sequencing of loads, with time delays involved, in the scenario of a LOCA followed by a delayed LOOP, and ensure that all loads will be sequenced within the time assumed in the accident analysis. (Section 8.3.1.11)*

Response: LOCA followed by LOOP

TVA to NRC letter dated December 6, 2010, "Watts Bar Nuclear Plant (WBN) Unit 2 – Safety Evaluation Report Supplement 22 (SSER22) – Response to Requests for Additional Information," (ADAMS accession number ML103420569) included the response to ***RAI 8.3.1.11***. That response stated, "A LOCA followed by a delayed LOOP is not a Design Basis Event for WBN."

The design basis for WBN assumes a simultaneous LOOP - LOCA. The Hydraulic Analysis does not support a LOCA with a delayed LOOP event; however, the logic is designed to ensure that loads are re-sequenced during a LOCA with a delayed LOOP, to prevent a block start on a diesel generator. This logic does not impact the sequencing for the design bases event, simultaneous LOOP - LOCA.

LOOP - Delayed LOCA.

When the LOOP occurs, the diesel will start, based on detection by the Loss of Voltage relay. Loads which sequence on due to a blackout signal (Charging Pump, Auxiliary Feedwater, Essential Raw Cooling Water Pump, Closed Cooling, etc.) will begin sequencing on.

When a subsequent LOCA signal occurs, the diesel will remain running and connected to the Shutdown Board. Loads which are required for accident mitigation and which have previously sequenced on to the Shutdown Board, due to the LOOP, will remain running. Loads which are not required for accident mitigation will be tripped. Remaining loads required for accident mitigation, which have not been sequenced on at the time of the LOCA, will have their timers reset to 0 and will sequence on at the appropriate time for the LOCA signal.

LOCA - Delayed LOOP

When the LOCA occurs, the loads which are not running in normal operation will block start. At the same time, the diesels will start on the LOCA signal, but will not tie to the Shutdown Board.

When a subsequent LOOP occurs, all sequenced loads will be stripped from the board from a Loss of Voltage (approximately 86%) signal. Once the loss of voltage relay has reached its set point and the diesel is available, the diesel breaker will close and the sequence timers will begin to time. The first large motor (Centrifugal Charging Pump) connects at 5 seconds and is followed by the remaining accident required loads. This provides assurance that the voltage has decayed on the boards and no residual out of phase reconnection occurs.

33. *TVA stated in Attachment 9 of its letter dated July 31, 2010, that certain design change notices (DCNs) are required or anticipated for completion of WBN Unit 2, and that these DCNs were unverified assumptions used in its analysis of the 125 V dc vital battery system. Verification of completion of these DCNs to the NRC staff is necessary prior to issuance of the operating license. (Section 8.3.2.3)*

Response: The applicable DCNs are as follow:

- DCN 53421 for the removal/abandonment of Reciprocating Charging Pump 2-MTR-62-101, supplied from 480V SHDN BD 2B1-B, Compt. 3B, has been issued.
- DCN 54636 for the cable modifications for Unit 2 AFWP Turbine Trip and Throttle Valve and Turbine Controls has been issued.

NRC will be notified when the physical work has been completed for these two DCNs.

34. *TVA stated that the method of compliance with Phase I guidelines would be substantially similar to the current Unit 1 program and that a new Section 3.12 will be added to the Unit 2 FSAR that will be materially equivalent to Section 3.12 of the current Unit 1 FSAR. (Section 9.1.4)*

Response: Amendment 103 to the Unit 2 FSAR added new Section 3.12 (*Control of Heavy Loads*). This new section is materially equivalent to Section 3.12 of the Unit 1 UFSAR.

Amendment 103 was submitted via TVA to NRC letter dated March 15, 2011, "Watts Bar Nuclear Plant (WBN) – Unit 2 – Final Safety Analysis Report (FSAR), Amendment 103."

36. *TVA should provide information to the NRC staff to enable verification that the SGBS meets the requirements and guidance specified in the SER or provide justification that the SGBS meets other standards that demonstrate conformance to GDC 1 and GDC 14. (Section 10.4.8)*

Response: Section 2.1.1, Safety Functions, of the SGB System Description Documents N3-15-4002 (Unit 1) and WBN2-15-4002 (Unit 2), state the following:

> "The SGB piping downstream of the containment isolation valves and located in the main stream valve vault room shall be TVA Class G. This piping is seismically supported to maintain the pressure boundary.
>
> The SGB piping located in the turbine building shall be TVA Class H."

The Unit 1 and Unit 2 SGB flow diagrams, 1, 2-47W801-2, also recognize the same TVA Class G and Class H class breaks located downstream of the safety-related SGB containment isolation valves.

The SGB flow diagrams and System Description document that TVA Class G and Class H classifications located downstream of the safety-related containment isolation valves are consistent with the data that was deleted in FSAR Section 10.4.8.1, Steam Generator Blowdown System - Design Basis, Item 6 Component and Code listings described above. It is also noted that NRC Quality Group D classification is equivalent to TVA Class G and H classifications as stated in the NUREG 0847 Section 3.2.2, System Quality Group Classification. Therefore, the design requirements in NRC GDC-1, Quality Standards and Records, and NRC GDC-14, Reactor Coolant Pressure Boundary are not challenged.

Amendment 104 to the Unit 2 FSAR will revise Table 3.2-2 to note that TVA Class G and H piping within the SGB System exists downstream of the safety-related containment isolation valves.

44. *TVA should provide additional information to clarify how the initial and irradiated RT_{NDT} was determined. (Section 5.3.1)*

Response: This response clarifies how the initial and irradiated RT_{NDT} values were determined for the Watts Bar Unit 2 reactor pressure vessel beltline materials. Unit 2 FSAR Section 5.2.4.1 established that the vessel was designed to 1971 Addenda of the ASME Code, an edition that predates the requirements to determine the unirradiated RT_{NDT}. (Those requirements were established in the Summer 1972 Addenda to the Code, Section III, Subarticle NB-2300, whereas the Watts Bar Unit 2 vessel was designed to an earlier version of the Code.) Because the tests performed to assess the adequacy of the fracture toughness predated the Summer 1972 Addenda to the Code, it was necessary to use the methods described in NRC Branch Technical Position (BTP) Materials Engineering Branch (MTEB) 5-2, "Fracture Toughness Requirements for Older Plants." For the Watts Bar Unit 2 vessel, the vessel shell materials were tested by the vessel fabricator using both drop-weight and Charpy impact test specimens. The drop-weight specimens were tested to determine the unirradiated nil-ductility transition temperature (NDTT) in accordance with ASTM E 208. In the ASME Code, Section III, Subarticle NB-2300, the NDTT is used with axial (weak) orientation Charpy test data to determine the initial (unirradiated) RT_{NDT}. For Watts Bar Unit 2, the orientation of the Charpy impact test specimens was in the tangential (strong) orientation rather than in the axial (weak) orientation currently required in NB-2300 to determine the initial RT_{NDT}. BTP MTEB 5-2 provides methods to determine the initial RT_{NDT} using the drop-weight and Charpy impact test results generated for the Watts Bar Unit 2 vessel shell forgings and welds. In summary, both drop-weight and Charpy impact specimens in the tangential (strong) orientation were tested and the results were evaluated to determine the initial RT_{NDT} following the methods in NRC BTP MTEB 5-2.

In addition to those tests performed by the vessel fabricator, unirradiated tests were performed on the Watts Bar Unit 2 reactor vessel surveillance program materials. Tests consisted of Charpy impact specimens from the intermediate shell forging and the core region metal that were oriented in both the tangential (strong) and axial (weak) orientations. When the surveillance program Charpy impact specimens are used with the drop-weight NDTT values obtained by the vessel fabricator, the initial RT_{NDT} values obtained using NRC BTP MTEB 5-2 are found to be conservative.

The irradiated RT_{NDT}, termed the Adjusted Reference Temperature (ART), is used to establish the Pressure-Temperature (P-T) limit curves for the vessel as documented in the Pressure and Temperature Limits Report (PTLR). The PTLR for Watts Bar Unit 2 is discussed in Unit 2 FSAR Section 5.2.4.3. The initial P-T limit curves are based on predictions of the effects of irradiation using the methods in NRC Regulatory Guide 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials." As post-irradiation test results become available from the evaluation of test specimens from the Watts Bar Unit 2 reactor vessel surveillance program, ASTM E 185-82, "Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels", uses those test results to assess the accuracy and conservatism of the predictions based on the methods of NRC Regulatory Guide 1.99, Revision 2. The reactor vessel irradiation surveillance program for Watts Bar Unit 2 is discussed in Unit 2 FSAR Section 5.4.3.6. The effect of irradiation is measured using the Charpy impact specimens. Note that there are no drop-weight test specimens irradiated as part of the Watts Bar Unit 2 surveillance program. The drop-weight specimens are used only for tests on the unirradiated material to determine the drop-weight NDTT.

In summary, both drop-weight and Charpy impact specimens (strong orientation) were tested and the results were evaluated to determine the initial (unirradiated) RT_{NDT} following the methods in NRC BTP MTEB 5-2. Additional tests performed as part of the reactor vessel surveillance program using Charpy impact specimens (weak orientation for the intermediate shell forging), and those data obtained following the ASME Code, Section III, Subarticle NB-2300 demonstrated the initial RT_{NDT} following the methods in

NRC BTP MTEB 5-2 to be conservative. The irradiated RT_{NDT}, termed the ART, will be determined using the methods in NRC Regulatory Guide 1.99. As post-irradiation test results become available from the reactor vessel surveillance program materials (the intermediate shell forging and the core region weld metal), those data will be used to assess the accuracy and conservatism of the predictions.

45. *TVA stated in its response to RAI 5.3.2-2, dated July 31, 2010, that the PTLR would be revised to incorporate the COMS arming temperature. (Section 5.3.2)*

Response: Revision 1 (effective August 12, 2010) to the Unit 2 System Description for the Reactor Coolant System (WBN2-68-4001) was revised to reflect the required revisions to the PTLR. Appendix B, Section 3.2 (*Arming Temperature*) states, "COMS shall be armed when any RCS cold leg temperature is ≤225°F."

46. *The LTOP lift settings were not included in the PTLR, but were provided in TVA's response to RAI 5.3.2-2 in its letter dated July 31, 2010. TVA stated in its RAI response that the PTLR would be revised to incorporate the LTOP lift settings into the PTLR. (Section 5.3.2)*

Response: Revision 1 (effective August 12, 2010) to the Unit 2 System Description for the Reactor Coolant System (WBN2-68-4001) was revised to reflect the required revisions to the PTLR. Appendix B, TABLE 3.1-1 (*Watts Bar Unit 2 PORV Setpoints vs Temperature*) contains the lift settings.

ENCLOSURE 2

Action Items From Appendix HH of NUREG-0847, Supplement 22 to Be Answered Later

Tennessee Valley Authority - Watts Bar Nuclear Plant - Unit 2, Docket No. 50-391

The item numbers used below correspond to item numbers in SSER 22, Appendix HH.

10. *Confirm that TVA has an adequate number of licensed and non-licensed operators in the training pipeline to support the preoperational test program, fuel loading, and dual unit operation. (Section 13.1.3)*

13. *TVA is expected to submit an IST program and specific relief requests for WBN Unit 2 nine months before the projected date of OL issuance. (Section 3.9.6)*

25. *Prior to the issuance of an operating license, TVA is required to provide satisfactory documentation that it has obtained the maximum secondary liability insurance coverage pursuant to 10 CFR 140.11(a)(4), and not less than the amount required by 10 CFR 50.54(w) with respect to property insurance, and the NRC staff has reviewed and approved the documentation. (Section 22.3)*

29. *TVA should provide the transmission system specifics (grid stability analyses) to the NRC staff. In order to verify compliance with GDC 17, the results of the grid stability analyses must indicate that loss of the largest electric supply to the grid, loss of the largest load from the grid, loss of the most critical transmission line, or loss of both units themselves, will not cause grid instability. (Section 8.2.2)*

30. *TVA should confirm that all other safety-related equipment (in addition to the Class 1E motors) will have adequate starting and running voltage at the most limiting safety related components (such as motor operated valves, contactors, solenoid valves or relays) at the degraded voltage relay setpoint dropout setting. TVA should also confirm that the final Technical Specifications are properly derived from these analytical values for the degraded voltage settings. (Section 8.3.1.2)*

32. *TVA should provide to the NRC staff the details of the administrative limits of EDG voltage and speed range, and the basis for its conclusion that the impact is negligible, and describe how it accounts for the administrative limits in the Technical Specification surveillance requirements for EDG voltage and frequency. (Section 8.3.1.14)*

35. *TVA should provide information to the NRC staff that the CCS will produce feedwater purity in accordance with BTP MTEB 5-3 or, alternatively, provide justification for producing feedwater purity to another acceptable standard. (Section 10.4.6)*

37. *The NRC staff will review the combined WBN Unit 1 and 2 Appendix C prior to issuance of the Unit 2 OL to confirm (1) that the proposed Unit 2 changes were incorporated into Appendix C, and (2) that changes made to Appendix C for Unit 1 since Revision 92 and the changes made to the NP-REP since Revision 92 do not affect the bases of the staff's findings in this SER supplement. (Section 13.3.2)*

ENCLOSURE 2

Action Items From Appendix HH of NUREG-0847, Supplement 22 to Be Answered Later

Tennessee Valley Authority - Watts Bar Nuclear Plant - Unit 2, Docket No. 50-391

43. *Section V of Appendix E to 10 CFR Part 50 requires TVA to submit its detailed implementing procedures for its emergency plan no less than 180 days before the scheduled issuance of an operating license. Completion of this requirement will be confirmed by the NRC staff prior to the issuance of an operating license. (Section 13.3.2.18)*

47. *The NRC staff noted that TVA's changes to Section 6.2.6 in FSAR Amendment 97, regarding the implementation of Option B of Appendix J, were incomplete, because several statements remained regarding performing water-sealed valve leakage tests "as specified in 10 CFR [Part] 50, Appendix J." With the adoption of Option B, the specified testing requirements are no longer applicable; Option A to Appendix J retains these requirements. The NRC discussed this discrepancy with TVA in a telephone conference on September 28, 2010. TVA stated that it would remove the inaccurate reference to Appendix J for specific water testing requirements in a future FSAR amendment. (Section 6.2.6)*

ENCLOSURE 3

Action Items From Appendix HH of NUREG-0847, Supplement 22 For NRC Inspection / Review

Tennessee Valley Authority - Watts Bar Nuclear Plant - Unit 2, Docket No. 50-391

The item numbers used below correspond to item numbers in SSER 22, Appendix HH.

1. *Review evaluations and corrective actions associated with a power assisted cable pull. (NRC safety evaluation dated August 31, 2009, ADAMS Accession No. ML092151155)*

2. *Conduct appropriate inspection activities to verify cable lengths used in calculations and analysis match as-installed configuration. (NRC safety evaluation dated August 31, 2009, ADAMS Accession No. ML092151155)*

4. *Conduct appropriate inspection activities to verify that TVA's maximum SWBP criteria for signal level and coaxial cables do not exceed the cable manufacturers maximum SWBP criteria. (NRC safety evaluation dated August 31, 2009, ADAMS Accession No. ML092151155)*

7. *Verify commitment completion and review electrical design calculations. (TVA letter dated October 9, 1990, ADAMS Accession No. ML073551056)*

9. *Confirm that education and experience of management and principal supervisory positions down through the shift supervisory level conform to Regulatory Guide 1.8. (Section 13.1.3)*

11. *The plant administrative procedures should clearly state that, when the Assistant Shift Engineer assumes his duties as Fire Brigade Leader, his control room duties are temporarily assumed by the Shift Supervisor (Shift Engineer), or by another SRO, if one is available. The plant administrative procedures should clearly describe this transfer of control room duties. (Section 13.1.3)*

12. *TVA's implementation of NGDC PP-20 and EDCR Appendix J is subject to future NRC audit and inspection. (Section 25.9)*

16. *Based on the uniqueness of EQ, the NRC staff must perform a detailed inspection and evaluation prior to fuel load to determine how the WBN Unit 2 EQ program complies with the requirements of 10 CFR 50.49. (Section 3.11.2)*

17. *The NRC staff should verify the accuracy of the WBN Unit 2 EQ list prior to fuel load. (Section 3.11.2.1)*

19. *The NRC staff should complete its review of TVA's EQ Program procedures for WBN Unit 2 prior to fuel load. (Section 3.11.2.2.1)*

21. *The NRC staff should confirm that the Electrical Penetration Assemblies (EPAs) are installed in the tested configuration, and that the feedthrough module is manufactured by the same company and is consistent with the EQ test report for the EPA. (Section 3.11.2.2.1)*

ENCLOSURE 3

Action Items From Appendix HH of NUREG-0847, Supplement 22 For NRC Inspection / Review

Tennessee Valley Authority - Watts Bar Nuclear Plant - Unit 2, Docket No. 50-391

38. *The NRC staff will confirm the availability and operability of the ERDS for Unit 2 prior to issuance of the Unit 2 OL. (Section 13.3.2.6)*

39. *The NRC staff will confirm the adequacy of the communications capability to support dual unit operations prior to issuance of the Unit 2 OL. (Section 13.3.2.6)*

40. *The NRC staff will confirm the adequacy of the emergency facilities and equipment to support dual unit operations prior to issuance of the Unit 2 OL. (Section 13.3.2.8)*

41. *TVA committed to (1) update plant data displays as necessary to include Unit 2, and (2) to update dose assessment models to provide capabilities for assessing releases from both WBN units. The NRC staff will confirm the adequacy of these items prior to issuance of the Unit 2 OL. (Section 13.3.2.9)*

42. *The NRC staff will confirm the adequacy of the accident assessment capabilities to support dual unit operations prior to issuance of the Unit 2 OL. (Section 13.3.2.9)*

48. *The NRC staff should verify that its conclusions in the review of FSAR Section 15.4.1 do not affect the conclusions of the staff regarding the acceptability of Section 6.5.3. (Section 6.5.3)*

49. *The NRC staff was unable to determine how TVA linked the training qualification requirements of ANSI N45.2-1971 to TVA Procedure TI-119. Therefore, the implementation of training and qualification for inspectors will be the subject of future NRC staff inspections. (NRC letter dated July 2, 2010, ADAMS Accession No. ML101720050)*

50. *TVA stated that about 5 percent of the anchor bolts for safety-related pipe supports do not have quality control documentation, because the pull tests have not yet been performed. Since the documentation is still under development, the NRC staff will conduct inspections to follow-up on the adequate implementation of this construction refurbishment program requirement. (NRC letter dated July 2, 2010, ADAMS Accession No. ML101720050)*

51. *The implementation of TVA Procedure TI-119 will be the subject of NRC follow-up inspection to determine if the construction refurbishment program requirements are being adequately implemented. (NRC letter dated July 2, 2010, ADAMS Accession No. ML101720050)*

ENCLOSURE 4

List of Regulatory Commitments

Tennessee Valley Authority - Watts Bar Nuclear Plant - Unit 2, Docket No. 50-391

1. TVA will qualify the MSIV solenoids to the Category I criteria. (response to action item 23)
2. NRC will be notified when the physical work has been completed for DCNs 53421 and 54636. (response to action item 33)
3. Amendment 104 to the Unit 2 FSAR will revise Table 3.2-2 to note that TVA Class G and H piping within the SGB System exists downstream of the safety-related containment isolation valves. (response to action item 36)

Attachment 1

Response to TVA for Core Loading Information and End of Cycle Assembly Burnup Data for Watts Bar Unit 2 Cycle 1

Response to TVA for Core Loading Information and End of Cycle Assembly Burnup Data for Watts Bar Unit 2 Cycle 1

Authored:

T. A. Jones (ND)*
Nuclear Design A

Verified:

R. N. Milanova (ND)*
Nuclear Design A

Approved:

D. E. Sipes*
Manager, Nuclear Design A

Attachment: 4 pages

*** Electronically approved records are authenticated in the Electronic Document Management System.***

Reference(s): 1) CN-WB01-010, Revision 1, “Revision 1 ** Watts Bar Unit 2 Cycle 1 (WBT01) ANC 8 Model and Core Loading Plan (CLP) Generation – Short Form Revision”

Figure 1 provides the core loading pattern for WBT01, while Figure 2 provides the control and shutdown rod locations. Figure 3 provides assembly average burnups for all core locations, at the maximum analyzed Cycle 1 burnup (17675 MWD/MTU).

FIGURE 1
WATTS BAR UNIT 2, CYCLE 1
REFERENCE CORE LOADING PATTERN

90°

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1					N03 FEED	N34 FEED	N10 FEED	N42 FEED	N13 FEED	N36 FEED	N23 FEED				
2			N24 FEED	N02 FEED	N50 FEED	L06 FEED	N58 FEED	L29 FEED	N63 FEED	L33 FEED	N52 FEED	N31 FEED	N05 FEED		
3		N18 FEED	N44 FEED	M03 FEED	L50 FEED	M17 FEED	L52 FEED	M20 FEED	L03 FEED	M34 FEED	L64 FEED	M36 FEED	N45 FEED	N19 FEED	
4		N15 FEED	M02 FEED	L13 FEED	M45 FEED	L43 FEED	M08 FEED	L45 FEED	M29 FEED	L38 FEED	M30 FEED	L41 FEED	M25 FEED	N16 FEED	
5	N09 FEED	N53 FEED	L28 FEED	M27 FEED	L31 FEED	M16 FEED	L01 FEED	M19 FEED	L49 FEED	M01 FEED	L26 FEED	M33 FEED	L15 FEED	N54 FEED	N12 FEED
6	N37 FEED	L58 FEED	M15 FEED	L56 FEED	M10 FEED	L47 FEED	M50 FEED	L69 FEED	M52 FEED	L46 FEED	M41 FEED	L42 FEED	M39 FEED	L54 FEED	N38 FEED
7	N01 FEED	N59 FEED	L14 FEED	M32 FEED	L60 FEED	M53 FEED	L12 FEED	M58 FEED	L30 FEED	M59 FEED	L53 FEED	M48 FEED	L36 FEED	N60 FEED	N22 FEED
8	N46 FEED	L57 FEED	M31 FEED	L59 FEED	M28 FEED	L68 FEED	M49 FEED	L07 FEED	M60 FEED	L67 FEED	M38 FEED	L08 FEED	M09 FEED	L21 FEED	N47 FEED
9	N08 FEED	N61 FEED	L11 FEED	M43 FEED	L22 FEED	M51 FEED	L35 FEED	M56 FEED	L34 FEED	M57 FEED	L16 FEED	M07 FEED	L51 FEED	N62 FEED	N07 FEED
10	N39 FEED	L39 FEED	M18 FEED	L61 FEED	M37 FEED	L37 FEED	M54 FEED	L17 FEED	M55 FEED	L27 FEED	M23 FEED	L10 FEED	M40 FEED	L09 FEED	N33 FEED
11	N29 FEED	N55 FEED	L19 FEED	M42 FEED	L48 FEED	M47 FEED	L62 FEED	M04 FEED	L20 FEED	M46 FEED	L04 FEED	M05 FEED	L02 FEED	N49 FEED	N27 FEED
12		N21 FEED	M13 FEED	L25 FEED	M06 FEED	L66 FEED	M14 FEED	L63 FEED	M22 FEED	L65 FEED	M21 FEED	L24 FEED	M11 FEED	N32 FEED	
13		N20 FEED	N41 FEED	M35 FEED	L23 FEED	M26 FEED	L44 FEED	M44 FEED	L40 FEED	M24 FEED	L32 FEED	M12 FEED	N48 FEED	N17 FEED	
14			N26 FEED	N06 FEED	N56 FEED	L18 FEED	N57 FEED	L05 FEED	N64 FEED	L55 FEED	N51 FEED	N30 FEED	N04 FEED		
15					N11 FEED	N40 FEED	N25 FEED	N43 FEED	N14 FEED	N35 FEED	N28 FEED				

Y YY	Assembly Identifier
Z-ZZ	Previous Cycle Location

0°

L	REGION 1 (2.100 $^{w}/_{o}$)
M	REGION 2 (2.600 $^{w}/_{o}$)
N	REGION 3 (3.100 $^{w}/_{o}$)

FIGURE 2
WATTS BAR UNIT 2, CYCLE 1
CONTROL AND SHUTDOWN ROD LOCATIONS

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1							SP								
2				SA		B		C		B		SA			
3					SD		SB		SB		SC				
4		SA		D				D				D		SA	
5			SC		A				SP		A		SD		
6		B				C		A		C				B	
7			SB		SP								SB		SP
8		C		D		A		D		A		D		C	
9	SP		SB								SP		SB		
10		B				C		A		C				B	
11			SD		A		SP				A		SC		
12		SA		D				D				D		SA	
13					SC		SB		SB		SD				
14				SA		B		C		B		SA			
15									SP						

90°

0°

Bank Identifier	Number of Locations	Bank Identifier	Number of Locations
A	8	SA	8
B	8	SB	8
C	8	SC	4
D	9	SD	4
		SP (SPARE)	8

FIGURE 3
WATTS BAR UNIT 2, CYCLE 1
ASSEMBLY AVERAGE BURNUP AT MAXIMUM ANALYZED CYCLE BURNUP (17675 MWD/MTU)

```
    #####################
   ##/ _ |#/ |/ / ___/##  Version  Job No.  Date/Time          Case No.   Ref. Time      Ref. BU      Title
  ##/ __ |/    / /#####   =======  =======  =================  =========  =============  ===========  =========
 ##/_/#|_/_/|_/|___/##    9.3.0       2147  03/22/11 11:55:01         16        10968.1        17675  WBT01 ANC
#####################


CA-Burnup          Assembly Burnup

                                                          180 deg
            1      2      3      4      5      6      7      8      9     10     11     12     13     14     15

  1                                  9777  11835  13123  12316  13123  11835   9777

  2                    10072  14620  16933  16986  18591  17543  18591  16986  16933  14620  10072

  3             10072  16055  17589  18595  19616  19446  19993  19446  19616  18595  17589  16055  10072

  4             14620  17589  18934  20143  20026  20695  20230  20695  20026  20143  18934  17589  14620

  5      9777  16933  18595  20143  20165  20880  20409  20966  20409  20880  20165  20143  18595  16933   9777

  6     11835  16986  19616  20026  20880  20400  20632  20374  20632  20400  20880  20026  19616  16986  11835

  7     13123  18591  19446  20695  20409  20632  20315  20567  20315  20632  20409  20695  19446  18591  13123

  8     12316  17543  19993  20230  20966  20374  20567  20287  20567  20374  20966  20230  19993  17543  12316

  9     13123  18591  19446  20695  20409  20632  20315  20567  20315  20632  20409  20695  19446  18591  13123

  10    11835  16986  19616  20026  20880  20400  20632  20374  20632  20400  20880  20026  19616  16986  11835

  11     9777  16933  18595  20143  20165  20880  20409  20966  20409  20880  20165  20143  18595  16933   9777

  12            14620  17589  18934  20143  20026  20695  20230  20695  20026  20143  18934  17589  14620

  13            10072  16055  17589  18595  19616  19446  19993  19446  19616  18595  17589  16055  10072

  14                   10072  14620  16933  16986  18591  17543  18591  16986  16933  14620  10072

  15                                 9777  11835  13123  12316  13123  11835   9777

             Max           Min
    Maximum  Loc  Minimum  Loc
    =======  ===  =======  ===
      20966  5-8     9777  1-5

End-Edit
```

Attachment 2

A Review of Electronic Components in a Radiation Environment of $\leq 5\text{x}10^4$ RADS

TVA 10697 (DNE-6-86) **DNE CALCULATIONS** **QA Record** 4

TITLE A Review of Electronic Components in a Radiation Environment of $\leq$ 5X10^4 RADS

PLANT/UNIT All Nuclear Plants

PREPARING ORGANIZATION EEB I&C

KEY NOUNS (Consult RIMS DESCRIPTORS LIST) EQ. INST. ACC. RAD. Mon.

BRANCH/PROJECT IDENTIFIERS 72186RDM

Each time these calculations are issued, preparers must ensure that the original (RO) RIMS accession number is filled in.

Rev	(for RIMS' use)	RIMS accession number
R0	860929C0016 ㉜	B43 '860721 903
R 1		~~B43 '86 0915 911~~
R __		
R __		

APPLICABLE DESIGN DOCUMENT(S) NA

SAR SECTION(S) NA

UNID SYSTEM(S) NA

Revision 0	R1	R2	R3
ECN No. (or Indicate Not Applicable) NA			
Prepared R. D. McKnight 9-12-86			
Checked Albert J. [illegible] 9-12-86			
Reviewed M R Belue 9-12-86			
Approved A. F. Pagano			
Date 9-15-86			
List all pages added by this revision.			
List all pages deleted by this revision.			
List all pages changed by this revision.			

Use form TVA 10534 if more space required.

Safety-related? Yes ☑ No ☐

Statement of Problem

To document the engineering basis for classifying the accident environment for this device(s) as (essentially) mild in accordance with 10CFR50.49 paragraph (c). This calculation will be used in the justification basis for instrument demonstrated accuracy calculations.

Abstract

These calculations contain an unverified assumption(s) that must be verified later. Yes ☐ No ☑

A review was made of a pertinent segment of available literature on radiation effects on electronic components, both from the perspective of the individual component and of the component assembly. Based on this review, an argument is presented that typical, nonselected electronic components used in nuclear plants will, with certain notable exceptions, tolerate a total radiation dose (total 40 years integrated dose plus accident dose) of 5X10^4 rads or less without significant degradation in their performance. Consequently, with respect to the radiation environment, the subject components, or assemblies comprised of these components, are in a mild environment as defined in 10CFR50.49(c).

☐ Microfilm and store calculations in RIMS Service Center. Microfilm and destroy. ☐

☑ Microfilm and return calculations to: H.C. COLLEY Address: W8D188 C-K

cc: RIMS, SL 26 C-K

TVA

B/P ID 72186RDM

Title: A Review of Electronic Components in A Radiation Environment of ≤ $5X10^4$ RADS

REVISION LOG

Revision No.	DESCRIPTION OF REVISION	Date Approved

TVA 10636 (EN DES-7-77)

CONTENTS

1.0 PURPOSE

The purpose of this calculation is to present a suitable and adequate argument to establish 5X10^4 rads as a low level threshold dose for radiation damage to electronic components typically used in nuclear power plant equipment. Then the electronic component, located in an otherwise benign plant environment and which is exposed to less than the threshold dose during its design life plus accident, would be excluded from the qualification requirement for radiation testing or further analysis of radiation effects. With respect to radiation, the electronic component could be considered in a mild environment and thus not in the scope of 10CFR50.49.

2.0 UNVERIFIED ASSUMPTIONS

There are no unverified assumptions used in this calculation.

3.0 METHODOLOGY

A review was made of a pertinent segment of available literature on radiation effects on electronic components, both from the perspective of the individual component and of the component assembly. Based on this review, an argument is presented that typical, non-selected electronic components used in nuclear plants will, with certain notable exceptions, tolerate a total radiation dose (total 40-years integrated dose, plus accident dose) of 5x10^4 rads or less without significant degradation in their performance. Consequently, with respect to the radiation environment, the subject components, or assemblies comprised of these components, are in a mild environment as defined in 10CFR50.49 (c).

Obviously, no comprehensive degradation model exists from which one could calculate an all-inclusive threshold for every electronic assembly (two or more electronic components). However, sufficient data is available to enable one to make general inferences which lead to reasonable judgments concerning the potential for radiation damage to electronic assemblies. Involved in this judgment exercise on a case-by-case basis are items concomitant with irradiation, such as notably radiation sensitive materials, circuit application, device function, useful life of devices, shielding, etc.

4.0 SCOPE OF INTEREST

The scope of interest in this review includes the following electronic components: resistors, potentiometers, capacitors, electron tubes, semiconductors, insulation and insulators, magnetic materials, relays, switches, printed circuit boards, terminal blocks, electrical connectors, transformers, electrical meters, and piezoelectric crystals.

5.0 COMMENTS ON SPECIFIC COMPONENTS

This section contains a number of comments which are deemed pertinent to the mild environment argument for electronic components exposed to $5X10^4$ rads or less. When considering an electronic assembly in a radiation environment, one can offer evidence on the individual components in the assembly and also evidence on the typical electronic assembly as a whole. Both sets of evidence help support the mild environment case. In this section and the remainder of this calculation, the reference from which a comment or argument was obtained will be given at the end of the comment. The reference will bn in the form (x)py or (x)ppy-z, etc. For example, "(1)p5" and "(3)pp3-10" indicate "reference 1, page 5" and "reference 3, pages 3 through 10," respectively.

5.1 Radiation Effects on Resistive Components

5.1.1 **Carbon-Composition Resistors** - Carbon-composition resistors are inherently the least stable member of the resistor family. In a representative experiment, nonenergized carbon-composition resistors were exposed to an integrated flux of approximately $4X10^{15}$ fast neutrons per square centimeter ($n\text{-}cm^{-2}$), an integrated thermal-neutron dose of $2.4X10^8$ nvt (nvt is neutrons per square centimeter per second "times" time), and a gamma exposure of $6.8X10^{10}$ ergs g^{-1}(C) (at a does rate of $3.9x10^4$ ergs per gram per second over a period of 20.83 days). Since one rad is radiation absorbed dose equivalent to 100 ergs of radiation energy per gram of the absorbing material, $6.8X10^{10}$ ergs g^{-1} is $6.8X10^8$ rads. In the experiment, the worst case change in resistance value (for resistors in the range of 100 ohms to 1 megohm) was a negative 6.7 percent. In another experiment, carbon composition resistors (10-K ohm range) were exposed to integrated fast neutron flux of 10^{13} $n\text{-}cm^{-2}$ and radiation dose of $8X10^8$ rads. The gamma dose caused an average increase in resistance of 0.86 percent. (1)pp16-18. See the discussion on reference 9 in subsection 5.1.3 (particularly Table 1) for additional information on carbon-composition resistors.

5.1.2 **Carbon-Film Resistors** - Two experiments are mentioned here involving carbon-film resistors. In one experiment, the gamma radiation dose was $8X10^6$ rads at a rate of 30 rads per second, and the carbon-film resistors changed (in resistance value) by an average of 0.40 percent. In the other experiment, carbon-film resistors from six leading manufacturers (resistance values ranged between 100 ohms and 1 megohm) were exposed to $4x10^8$ rads, gamma. Resistance changes in five makes varied between 0.5 and 1.8 percent. The sixth make of resistor changed by 5 percent. (1)pp18.19.

5.1.3 **Metal-Film Resistors** - Most available data show that metal-film resistors are less sensitive to nuclear radiation than either carbon-composition or deposited-carbon-film resistors. (1)pp22-27, (3)pp568-573. According to reference 1, a 1958 Bell Telephone Laboratories' report indicated that catastropic failure had been observed in certain metal-film resistors. No mention was made in reference 1 to the failure mechanism or the radiation dose (at which the resistors failed) reported in the Bell Laboratories' report. Reference 1 implies that the failed metal-film resistors in the Bell report were a minority, as indicated by the quote from page 22: "The physical differences between the failed resistors and most film-resistor types made the former more susceptible to radiation damage." Other experiments reported on in reference (1) showed that unspiraled and uncoated resistors exhibited the greater number of failures and the largest resistance changes. The following quote is from page 24 of reference 1: "Broad differences in effects of radiation between coated resistors and resistors protected with an epoxide molding seem to point out that exposed elements are sensitive to radiation." One should note that the date on reference 1 is October 1, 1964, and that the date on the Bell Laboratories' report (mentioned immediately above) was December 31, 1958. Great strides in fabrication technology in metal-film resistors have been made since that time. Metal-film resistors for probably the last 15 years or more have been protected with a glass, epoxy, or other coating. The probability of having metal-film resistors in TVA nuclear plant instrumentation identical to those "catastropically failing" in the 1958 Bell report mentioned above is quite remote. The bulk of data reported in references 1 and 3 support the statement that metal-film resistors are less sensitive to nuclear radiation than either carbon-composition or deposited-carbon-film resistors.

A number of other references also help substantiate the claim that metal-film resistors are less sensitive to nuclear radiation than either carbon-composition or deposited-carbon-film resistors. Some of these references will now be discussed. Reference 7 reports on a survey on aging of electronic components such as semiconductors, capacitors, and resistors used in safety-related instrumentation Carbon composition, film (glaze metal), and wire-wound resistors were among the "typical electronic components" listed as being used in pressure transmitters and acoustic accelerometer preamplifiers in reactor containment. Reference 7 states that pressure transmitters constitute approximately 80 percent of the signal conditioning equipment used in containment. According to reference 7, the radiation tolerance for resistors is typically 10^8 to 10^{11} rad (Si) and 10^{14} to 10^{16} neutrons/cm^2 (n/cm^2).

The following is an excerpt from reference 8:

Resistors are among the most stable electronic components in radiation environments. Radiation damage is very dependent upon resistor type and construction. Metal film resistors are recommended for hardened circuits since they provide radiation hardness of approximately 10^9 rad and 10^{16} n/cm^2.

Reference 9 is concerned with research being performed by Wyle Laboratories under the sponsorship of the Electric Power Research Institute (EPRI), and specifically discusses the supplemental program which added radiation as an aging mechanism. The paper reports on component selection, seismic test requirements, aging , and test results. The following generic types of components were selected: resistors, diodes, integrated circuits, transistors, optical couplers, relays, capacitors, terminal blocks, and printed circuit boards. Table 1 below is table II from reference 9:

Table 1 Aging Treatment Combinations

	Aging Treatments							
	U	T	C	R	TC	TR	CR	TCR
Resistors, Wire Wound	20	12	0	0	12	10**	20**	10**
Resistors, Carbon Composition	160	85	37	40* 90**	86	89**	30**	47* 42**
Resistors, Metal Film	109	38	23	2* 2**	28	30**	107**	11* 29**
Diodes	10	10	10	3* 7**	10	7* 8*	8* 7**	7* 8*
Integrated	10	10	10	7* 8**	10	15**	8* 7**	15**
Transistors	15	5	5	5	10	5* 5**	5* 5**	10* 10**
Optical Couplers	2	4	4	2	2	2**	2**	6**
Relays, Printed Circuit Board Mounted	2	0	1	0	0	0	1**	1* 2**
Relays, Panel Mounted	3	0	3	0	0	0	0	3* 3**
Capacitors, Tantalum	20	10	0	0	10	10**	20**	10**

	U	T	C	R	TC	TR	CR	TCR
Capacitors, Ceramic	25	12	0	0	12	13**	25**	13**
Terminal Blocks	5	0	5	0	0	5**	0	5**
P.C. Boards	4	3	2	1**	3	4**	3**	2* 3**
Sockets, Integrated Circuit	13	14	15	15**	14	15**	15**	15*
Sockets, Transistor	10	0	10	0	0	10**	0	10*
Sockets, Relay	0	0	0	5**	0	0	1* 5**	4* 5**

Legend:

* Items irradiated to 10^5 rads
** Items irradiated to 10^6 rads
U = Unaged control group
T = Time temperature aging only
C = Cycle aging only
R = Radiation aging only
TC = Time temperature and cycle aging
TR = Time temperature and radiation aging
CR = Cycle and radiation aging
TCR = Time temperature, cycle and radiation aging

The components listed in Table 1 above were installed in a test cabinet and exposed to Co-60 in two exposures. The first exposure was at a dose rate of $2X10^4$ rads per hour. This exposure continued until the integrated dose was $1X10^5$ rads. Certain components were then removed from the test cabinet. Radiation exposure then continued on the remainder of the components at a dose rate of $2X10^5$ rads per hour until the integrated dose was $1X10^6$ rads. The components were connected to power sources, signal generators, and monitored throughout the radiation exposure. No failure resulted from the radiation exposure.

Reference 10 reports on the application of a radiation-hardened preamplifier used in a relief-valve monitoring system for nuclear power plants. One of the design objectives in developing the preamplifier was to use commercial, off-the-shelf components with inherent radiation tolerance. In the course of developing the preamplifier, radiation testing was performed on 90 bipolar transistors, junction field-effect transistors (JFETs), diodes, and zener diodes at a dose rate of $3.8X10^6$ rads (Si) per hour for a total dose of $2.2X10^8$ rads (Si) using a Co-60 source. All devices were actively irradiated, and provisions were made for the monitoring of bipolar transistor base currents, JFET gate currents, and diode voltage drops during the irradiation. Circuitry for biasing and monitoring was provided by two printed circuit boards (PCBs). The PCBs were made of G-30 polyimide material, and bias resistors were RN55C-type metal-film resistors which were within ±2% of their nominal valves after irradiation. The interest at this point in this calculation is on the metal-film resistors. Results on the other devices will be discussed in other sections of this calculation.

5.1.4 Precision Wire-Wound Resistors - Experiments and studies prove that precision wire-wound resistors suffer no noticeable degradation under steady-state nuclear radiation. One experiment showed a change (of resistance value) of 0.9 percent or less for a gamma dose of $8.77X10^6$ rads. (1)p27. See the discussion on reference 9 in subsection 5.1.3 (and note Table 1) for additional information on wire-wound resistors.

5.1.5 Thermistors - In an experiment to determine radiation effects on thermistors, three types of thermistors (rods, beads, and disks) were exposed in a nuclear environment to a total integrated fast-neutron flux of $5.5X10^{12}$ $n\text{-}cm^{-2}$ and a gamma dose of $2X10^{12}$ rads. Transient and post irradiation measurements of current-voltage values indicated that no changes in the negative-temperature coefficients were observed. (1)p29.

5.1.6 Additional Radiation Tolerance Information - Table 2 below is from page 722 of reference 8.

Table 2. Electronic Component Radiation Tolerance Levels

Component	Gamma [rad(Si)]	Neutron [n/cm2]
Semiconductors		
Bipolar	10^4-10^6 $(10^7)^a$	10^{12}-10^{13} 10^{15}

Op-Amp	10^5 $(10^6$-$10^7)$	10^{12}-10^{13} (10^{14})
JFET	10^7	10^{16}
Diodes	10^6-10^8	10^{12}-10^{15}
MOS	10^3-10^4 (10^6)	10^{15}-10^{16}
Capacitors[b]	10^7-10^{10}	10^{15}-10^{16}
Resistors	10^7-10^{11}	10^{14}-10^{16}

a) Bracketed numbers are for selected radiation-hardened components.

b) Some plastic, paper, and aluminum electrolytle capacitors have lower radiation tolerance levels.

Note from Table 2 above that the radiation tolerance level of resistors is listed as 10^7-10^{11} rads (Si).

5.1.7 A review of subsections 5.1.1 through 5.1.6 above indicated resistors (which are commercially available and present in typical electronic assemblies) can tolerate a total dose of at least $1X10^5$ rads without substantial degradation in circuit performance. This conclusion also includes potentiometers.

5.2 Radiation Effects on Capacitors

Dimensional change of the interelectrode spacing is the principal cause of capacitance changes during irradiation. The dimensional change is most pronounced when radiation-sensitive materials, such as organics, are used in one or more parts of the capacitor's construction. Pressure build-up from gas evolution and swelling causes physical distortion of the capacitor elements and results in0changes in interelectrode spacing. In general, the transient capacitance change will be larger and more positive than the permanent change. The transient effects are largely dependent on the flux rate, and the permanent effects are mainly the result of total exposure. (1)p.35. See Table 2 in subsection 5.1.6 above for information (in addition to that presented in subsections 5.2.1through 5.2.6 below.)

5.2.1 Glass-Dielectric Capacitors - In the family of capacitors, glass and vitreous-enamel capacitors have shown the greatest resistance to radiation. Various radiation studies indicate only a slight radiation effect. After exposure to a gamma dose of $6.1X10^8$ rads, changes in capacitance of 2.0 percent or less were noted. (1)p36, (3)pp585-589.

5.2.2 Mica-Dielectric Capacitors - During irradiation, a small change in capacitance (in either direction) is typical of mica capacitors. Postirradiation tests have indicated that these changes are generally permanent. Measurements of the effective insulation resistance during radiation show a substantial decrease, with complete recovery when the capacitors are removed from the radiation environment. (1)p37, (3)p590. Table 2 on pp42-44 in reference 1 tabulates the radiation effects on mica-dielectric capacitors from a number of experiments. Negligible changes in capacitance were noted at total radiation exposures of $1X10^7$ rads or less.

5.2 3 Ceramic-Dielectric Capacitors - A ceramic-type capacitor consists basically of a ceramic dielectric with a thin metallic film on either side for the electrodes (or capacitor plates). Two basic types are available, i.e., general purpose and temperature compensating, with several body designs: disk, tubular, standoff, and feed-through. In one experiment, temperature-compensating ceramic capacitors received a gamma dose of $1.47X10^{11}$ rads. The capacitance of these units increased during irradiation with the increase varying between 3.7 and 18.8 percent of the initial value, depending on the measurement interval and capacitor being observed. The changes resulting from radiation on general-purpose ceramic capacitors are negligible when considering the extremely wide tolerances that capacitors of this type have. The capacitance of general purpose ceramic capacitors, with few exceptions, decreases during irradiation, and almost complete recovery follows their removal from the radiation environment. In one experiment, 12 general purpose ceramic capacitors received a gamma dose of $4.84X10^{10}$ rads. During the irradiation, the changes in capacitance of the 12 units varied between +2.9 and -13.1 percent of their initial values. These units recovered to within +0.4 and -7.0 percent of their initial values when removed from the radiation environment. (1)pp41.46. (3)pp595-601. See Table 1 in subsection 5.1.3 above for additional information on ceramic capacitors.

5.2.4 Paper-Dielectric Capacitors - Radiation-effects experiments on paper and oil-impregnated paper capacitors have indicated that they are more sensitive to radiation than the inorganic types (ceramic, glass, and mica) by factors of 10^2 to 10^3. One experimental work consisted of subjecting 100 paper dielectric capacitors to combined environments of high temperature and nuclear radiation. The gamma dose was $9.0X10^8$ rads. Most of the capacitors exceeded their lower tolerance level of -20 percent at approximately $3.41X10^7$ rads. (1)pp47,53, (3)pp601-605. The only materials in this class of capacitors which are not metal are those associated with the dielectric or coating. In accordance with subsection 5.5.2, the only materials (either organic or inorganic) which have radiation damage thresholds less than $1X10^5$ rads are fluorcarbons.

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5.2.5 Plastic Dielectric Capacitors - The materials commonly used in plastic dielectric capacitors are polystyrene, polyethylene, and mylar (polyethylene terephthalate). Generally, low-voltage units are used without impregnation or liquid fill. Applications for plastic-dielectric capacitors are typically the same as those for paper dielectric capacitors. An experiment was performed in which mylar foil capacitors received a gamma dose of $4.8X10^8$ rads. The capacitance and dissipation factors were not seriously affected by the irradiation. The capacitance remained within 2.0 percent of the initial value. The dissipation factor increased to values of between 30 and 60 percent above their initial values during exposure, but recovered to 10 percent above the initial value when the radiation source was removed. (1)pp55.63, (3) pp605-613. The only materials in this class of capacitors which are not metal are these associated with the dielectric or coating. In accordance with subsection 5.5.2, the only materials (either organic or inorganic) which have radiation damage thresholds less than $1X10^5$ rads are fluorocarbons.

5.2.6 Electrolytic Capacitors - Data from radiation-effects experiments with tantalum and aluminum electrolytic capacitors indicates that both types may be capable of surviving extended exposure to intense radiation. As a part of one program, aluminum and tantalum electrolytic capacitors were given a gamma dose of $5.7X10^6$ rads. The aluminum capacitors decreased (with respect to initial values) an average of 6 percent during irradiation, and essentially recovered to preirradiation values within six days after irradiation ceased. The tantalum capacitors decreased an average of 9.7 percent during irradiation, and recovered after 10 days (after radiation source was removed) to a value 4.7 percent below the initial value. (1)p71, (3)pp613-626. See Table 1 in subsection 5.1.3 above for additional information (from reference 9) on electrolytic (tantalum) capacitors.

5.2.7 Summary Comments on Capacitors - Based upon the information presented in subsections 5.2. through 5.2.6 above, the conclusion is that capacitors will tolerate a total dose of at least $1X10^5$ rads with no significant degradation.

5.3 Radiation Effects on Electron Tubes

For convenience of presentation in this calculation, electron tubes will be divided into four classes: (1) vacuum tubes, (2) gas tubes, (3) light-sensitive tubes, and (4) microwave tubes. Each will be discussed below and a summary conclusion made in subsection 5.3.5.

5.3.1 Vacuum Tubes - Radiation-damage studies indicate that vacuum tubes are affected in three ways due to irradiation: (1) formation of a high residual radioactivity in various materials used in tube construction, (2) appreciable changes in electrical characteristics during and after irradiation, and (3) increased fragility, or in many cases, complete mechanical damage. (1)p80. A comprehensive study was conducted by the Admiral Corporation for the most common types of vacuum tubes. A summary of the results from the Admiral studies and other investigations iu given in Table 7 (pages 84-90) of reference 1. Also, see pp.538 and following in reference 3. Mechanical damage to vacuum tubes in the form of fracturing or cracking of the tube envelope, failure of glass-to-metal seals, and cathode or filament support failures appear to be the main cause of major concern during exposure to nuclear radiation. (1)p80. A review of Table 7 in reference 1 indicates no evidence of tube failure for total gamma doses of $1X10^5$ rads or less. With respect to the failure of the glass-to-metal seals, it is noted that a synthetic organic material (such as Bakelite, i.e., phenolics, polysulfone, etc.) might be involved in such a seal or in the base of the tube. If so, this poses no problem since only one of the synthetic organics has been found to have a radiation degradation threshold consistently below 10^5 rads but above 10^4 rads, namely fluorocarbons. (11) pS-2.

5.3.2 Gas Tubes - The principal difference between a gas tube and the vacuum tube is the presence of an inert filling gas in the region between the plate and the cathode of the device. In a radiation environment, the major causes of malfunction, excluding mechanical or physical damage, are related to radiation effects on the gas. Table 8 (pages 92-93) in reference 1 is a summary of many reports on radiation effects on gas tubes.

5.3.3 Light-Sensitive Tubes - Electron tubes whose operation is a function of the transparency of the glass envelopes encounter a loss of sensitivity from darkening of the glass when subjected to nuclear radiation. No physical damage to light-sensitive tubes other than the glass discoloration has been observed at exposures of $5.5X10^{12}$ fast n-cm $^{-2}$ and $7.2X10^6$ rads. STudies with irradiated photomultiplier-type tubes indicate that ionization-induced current was observed at gamma exposure rates between 1 and 10^4 rads per hour. This current was found to vary as a linear function of the exposure rate. At exposure rates of approximately 10^4 rads per hour, the induced current exceeded the rated tube current. (1)p95. However, in a mild environment the dose rate should be considerably below 10^4 rads per hour.

5.3.4 Microwave Tubes - Reference 1 reports an experiment in which a number of Klystrons were exposed to a gamma radiation dose of $9.6X10^8$ rads. Beam current, reflector voltage, power output, operating frequency, and tuning range were measured before, during, and after irradiation. The reported results indicated that all of the Klystrons survived irradiation without change in their operating characteristics. (1)p99.

5.3.5 Summary Conclusion on Radiation Effects on Electron Tubes

Based upon a review of the information discussed in subsections 5.3.1 through 5.3.4 above, it is concluded that electron tubes can tolerate a total gamma radiation dose of at least $1X10^5$ rads without fracture of glass and with no more than ±20% change in tube characteristics.

5.4 Radiation Effects on Semiconductors

Semiconductor devices function through designed imperfections in their crystal structure and some can be quite sensitive to further disruption of those structures by displacement processes. Damage to inorganic/metallic materials is primarily related to physical displacement of electrons and/or atoms and consequent disruption of the crystal lattice structure of the absorbing material. (3)pS-1.

There are three types of radiation to review when considering the effects of nuclear radiation on semiconductors: thermal neutrons, fast neutrons, and gamma rays. Since the equipment under consideration in this review will be in plant locations considered "essentially mild" and out of active "neutron environments," only the effects of gamma radiation will be considered here. The interaction of gamma rays with matter is primarily through three mechanisms,namely, the photoelectric effect, Compton scattering, and pair production. (12)p21. Tho gamma radiation from its passage through the semiconductor material does not produce directly atomic lattice displacements. The gamma rays, on passing through matter, lose their energy mainly by the photoelectric effect and Compton scattering. Gamma ray bombardment of solids results primarily in electronic excitation and ionization. However, it is possible that the electrons of the photoelectric and Compton process may possess sufficient energy to cause atomic displacement. The most important electrical effect that results from the exposure of semiconductors to nuclear radiation is the decrease in minority-carrier life time due to lattice displacement. Depending upon the structure of the device, germanium devices have shown that they can withstand up to an order of magnitude more nuclear radiation than a comparable silicon device. (1)pp 100-102.

5.4.1 Diodes - In general, the following effects results from exposing diodes to nuclear radiation:

a. With a constant voltage across the diode, the forward current will decrease with radiation exposure.

b. The reverse leakage current and reverse break-down voltage both increase with exposure to radiation.

c. Switching time, which is directly dependent on minority-carrier lifetime, will naturally decrease with radiation. (1)pp104,105.

A number of different types of diodes will be discussed in subsections 5.4.1.1 through 5.4.1.7 below. Subsection 5.4.1.8 will then give a general conclusion on the radiation resistance of the entire class of diodes.

5.4.1.1 General Diodes - The general diode group is very loosely defined and contains a wide variety of diodes. This group of diodes performs rectification at low power and relatively low speed, and has no special characteristics. Table 12, page 107 in reference 1, tabulates the results of a number of experiments on general diodes. In the process of ascertaining the useful life of a semiconductor device, one must take into account the circuit application or function required of the device. Failure of a device is generally produced not by a sudden or abrupt change in device characteristics during irradiation, but is usually by a gradual change in characteristics. The failure point is defined as the exposure required to change these device parameters such that they are outside specified tolerance limits for a particular application. In the case of general diodes (general-purpose diodes) and rectifier diodes, rather wide tolerances are allowable for most applications. (3)pp498,500.

5.4.1.2 Switching Diodes - A switching diode is a diode with specified turn-on and turn-off characteristics suitable for use in a computer or switching circuitry. Table 13 (pages 109, 110) in referenced 1 summarizes the results of a number of experiments on radiation effects on switching diodes. Switching diodes are characterized by: (1) a short storage time (which results in a short minority-carrier lifetime); (2) a low diode capacity (which usually results from a small diode area); and (3) a low series resistance (obtain by using a semiconductor material of low resistivity). Each of these factors contribute to making diodes which are relatively radiation resistance. (1) p108. Reference 10 reports exposing three IN914 switching diodes to $2.2X10^8$ rads with less than 1% change in the voltage drop across the diode.

5.4.1.3 Rectifiers (Power Diodes) - A diode which is specifically intended for rectifier applications and dissipates 1/2 watt or more of power will be considered a power diode or rectifier.

Because of structural and material difference, selenimum appears to be more radiation resistant than either germanium or silicon. (1)p108. Table 14 (page 111) in reference 1 gives data on a number of experiments on radiation of rectifiers. Note from subsection 5.4.1.1 above that rectifier diodes can have rather wide tolerance which are allowable for most applications.

5.4.1.4 Voltage Reference Diodes - The term "zener diode" has become widely used for silicon reference voltage diodes. Table 15 (page 113) in reference 1 summarizes the results of a number of radiation experiments on voltage reference diodes. A review of Table 15 indicates that reference voltages may change as much as 5.8 percent in some units as the gamma dose approaches $1X10^6$ rads, but the change in the majority of reported cases was much less. Reference 10 reports exposing three each IN4623, IN5229B, and IN5527A zener diodes to $2.2X10^8$ rads (Si). The voltage drops across the diodes changed less than 1% because of the exposure.

5.4.1.5 Microwave Diodes - Microwave diodes operate in the range of frequencies from 1,000 to 100,000 megahertz and are designed for insertion into a wave guide or coaxial line. In general, microwave diodes are relatively radiation resistant. Some diodes constructed with PIN junctions are being used as microwave limiters. This type of diode can be considered very sensitive to radiation. Table 16 (page 114) in reference 1 gives data on several microwave diodes exposed to radiation. Reference 3 (page 504) reports an 1N23B microwave diode being observed using rf measurements over a period of 9 hours exposed to $2X10^7$ ergs per gram (C) per hour. This amounts to a total dose of $1.8X10^6$ rads. No changes were observed in the noise figure of the diode during the exposure.

5.4.1.6 Tunnel (Esaki) Diodes - Table 17 (pages 117,118) in reference 1 is a tabulation of summaries of results of radiation tests on a number of tunnel diodes. A review of Table 17 indicates that very little gamma radiation data was given in the table. However, consider the following:

a. The initial peak current in a tunnel diode is due to electrons tunneling from the conduction to the valence bands and is independent of carrier lifetime. (1) p115.

b. Tunnel diodes have a very narrow junction and high impurity concentrations in p-type and n-type regions. This fact helps make these devices radiation resistant. (1) p115.

c. The following is an excerpt from pages 66-67 of reference 13:

One of the most important features of the tunnel diode is its resistance to nuclear radiation. Experimental results have shown tunnel diodes to be at least ten times more resistant to radiation than transistors. Because the resistivity of tunnel diodes is so low initially, it is not critically affected by radiation until large doses have been applied. In addition, tunnel diodes are less affected by ionizing radiation because they are relatively insensitive to surface changes produced by such radiation.

5.4.1.7 Silicon Controlled Rectifiers - The silicon controlled rectifier (SCR) is a three-terminal, four-layer device with conduction characteristics that are analogous to a thyratron. One can visualize the SCR as consisting of overlapping NPN and PNP transistors. The current transfer ratio of both transistors is added together for the composite rectifier. Radiation-induced defects reduce these two transfer ratios such that the required gate current, holding current, and breakover voltage should all increase with radiation and at exposures comparable to damage exposures in silicon transistors. (1) p115. Approximate levels of SCR radiation tolerance have been determined through various tests performed on the General Electric C35 (2N685 series). Critical levels have been shown to be 10^{14} nvt for fast neutron bombardment and $5X10^5$R per second for gamma radiation. (14),p559. Since in air 1 rad equals 1.14 Roentgen, the critical exposure rate of $5X10^5$ R per second becomes $4.385X10^5$ rads per second. In reference 1, page 115, the statement is made: "Table 18 is a summary of reports on silicon controlled rectifiers. It can be seen that they fail between 10^{12} and 10^{13} ncm^{-2}." However, the following statement from reference 14, page 559, refutes the statement immediately above: "Early studies, concerning the radiation tolerance of semiconductor devices, indicated that thyristors were more susceptible to a degradation in electrical characteristics than bipolar transistors. This has recently been shown to be an invalid conclusion." The SCR is the senior and most influential member of the thyristor family of semiconductor components. Younger members of the thyristor family include the triac, bidirectional diode switch (diac), the silicon controlled switch (SCS), the silicon unilateral devices like the LASCR, the complementary SCR, the programmable unjunction transistor (PUT), and the "assymetrical trigger." As indicated earlier in this subsection, the approximate critical level of SCR radiation tolerance has been shown to be 10^{14} nvt. "nv" is a unit describing neutron flux in terms of neutrons per square centimeter per second (n cm^{-2} sec^{-1}), and "nvt" is the associated time-integrated neutron flux in terms of n cm^{-2}. From page 55 of reference 3,

1 rad/hr equals $8.3X10^4$ n cm^{-2} sec^{-1}

This translates into 1 rad equals $2.988X10^8$ n cm^{-2}. Thus, the approximate critical radiation tolerance level (of an SCR) given above, 10^{14} nvt, converts to $3.35X10^5$ rads.

5.4.1.8 <u>Additional Comments and Conclusions on Radiation Effects on Diodes</u> - Reference 9 reported that diodes were exposed to $1X10^6$ rads gamma without failure (see Table 1 in subsection 5.1.3 above). Reference 15 reports that FDR600 diodes were exposed to a total gamma dose of $2.5X10^7$ rads (Si) and still functioned acceptably in the circuit in which they were used.

Based upon the material presented immediately above and in subsections 5.4.1.1 through 5.4.1.7 above, it is concluded that semiconductor diodes can tolerate a total radiation dose of at least $1X10^5$ rads with no degradation beyond the acceptable tolerance limits of the applications in which the diodes are used.

5.4.2 <u>Transistors-Conventional (Bipolar)</u> - The parameters of transistors are affected not only by the radiation-induced defects in the bulk material but also by the surface effects caused by ionizing radiation. The changes occurring in the bulk material usually are the more permanent damage. As far as the changes in the electrical operation of the device are concerned, the principal effect is the decrease in current gain. Although some changes may be seen in the punch-through voltage, junction-depletion-layer capacitance, junction breakdown voltage, base spreading resistance, saturation voltages, collector body resistance, and leakage currents, the reduction in current gain will generally limit the usefulness of the transistor long before the other changes become a serious problem As radiation exposure increases, leakage currents typically increase. (1) pp115, 122, 123. For discussion purposes here, five groupings of bipolar transistors will be mentioned in the following subsections.

5.4.2.1 <u>General or Audio Transistors</u> - The general or audio class of transistor is a general class, and includes the audio transistors and those transistors that are bipolar in nature and do not fit into any of the remaining four groups. Since the class is so general, there is a wide variation in the results of radiation experiments (as seen in Table 21, page 128 of reference 1).

5.4.2.2 <u>Power Transistors</u> - The power transistors are used mainly in high current applications (greater than 1 ampere). This device typically has a thick base and is the least radiation resistant in the bipolar transistor family. See Table 22, page 129 of reference 1.

5.4.2.3 <u>High-Level Switching Transistors</u> - These are transistors that switch loads greater than 1 ampere. These unit show slightly better radiation resistance than the power or general transistors. See Table 23 (pages 130-132) in reference 1.

5.4.2.4 <u>High-Frequency Transistors</u> - This group of transistors have characteristics for high frequency operation at low currents. They generally have thinner bases and less junction capacitance than the other groups of transistors discussed here. As a result high frequency transistors show a better resistance to radiation. See Table 24 (pages 133-135) in reference 1.

5.4.2.5 <u>Low-Level Switching Transistors</u> - These are transistors which switch currents below 1 ampere. These devices apparently have the best radiation resistance of any of the conventional transistor groups. See Table 25 (pages 136-141) in reference 1.

5.4.2.6 <u>Additional Comments on Bipolar Transistors</u> - Reference 9(see Table 1 in subsection 5.1.3 above) reports on transistors exposed to total doses of as high as $1X10^6$ rads without failure. Tables 2, 3, 4, and 5 of reference 10 tabulate bipolar transistor current gain (also bias conditions) after a $2.2X10^8$ rads (Si) gamma dose for NPN medium frequency, NPN high frequency, PNP medium frequency, and PNP high frequency transistors, respectively. Reference 10 reports that, after the $2.2X10^8$ rads (Si), all devices were operational with B values greater than 10, and F_T (common emitter current gain bandwidth product) did not degrade significantly.

5.4.2.7 <u>Summary Comments on Bipolar Transistors</u> - Tables 21 through 25 in reference 1 summarize the results of many radiation tests on various types of bipolar transistors (16 manufacturers are represented). The criterion used to obtain the exposure levels was that most of the devices in a given transistor class should show a common emitter current gain (β) that (at the specified exposure) was 10 percent or less of the initial value. Pages 122-125 of reference 1 indicate that, to a good first order appropriation, the common base current gain (α) has a linear dependence on the integrated fast neutron flux. While the degradation mechanism may differ for fast neutron and gamma exposures, the resultant changes in electrical properties of transistors is virtually the same. The dominant change is a decrease in current gain (see 5.4.2 above).

Since $\beta = \frac{\alpha}{1-\alpha}$, one can infer that β is linearly dependent on the integrated gamma dose, to a good first order approximation. From a review of Tables 21 through 25 in reference 1, it is noted that generally β is approximately $0.1\beta_0$ (where β_0 is the initial value of β prior to irradiation) when the integrated gamma dose is greater than $1X10^7$ rads. A study of Figure 32 on page 125 of reference 1 shows that the current gain decreases from approximately 90% of β_0 to approximately 10% of β_0 in two decades of time-integrated neutron flux. Using the reasoning discussed immediately above, one can state then that generally β will be at least 90% of β_0 at $1X10^5$ rads of gamma radiation. For all but the most critical applications of transistors, a decrease in β of 10% should be tolerable. Hence, it is concluded that bipolar transistors can tolerate an integrated gamma dose of $1X10^5$ rads and still perform satisfactorily.

5.4.3 Transistors-Nonconventional - The class of nonconventional transistors, as used in this calculation, includes those devices that do not have the structure and characteristics of the bipolar transistor (see subsection above). This class includes the field-effect as well as the unijunction transistors. The field-effect transistor (FET) depends on the majority-carrier lifetimes and not the minority-carrier lifetimes. Hence, it can be expected that the device characteristics should degrade with radiation exposure at a slower rate than conventional (biopolar) transistors. (1) p127.

The above is true for junction field-effect transistors (JFETs). Table 2 (see subsection 5.1.6 above) in reference 8 lists the radiation tolerance levels of JFET and MOS semiconductors as 10^7 rads (Si) and 10^3-10^4 rads (Si), respectively.
Reference 16 reports on radiation testing performed on a number of specific memory devices representative of the major large scale integration (LSI) process technologies. Many of these devices were MOS devices. Failure rates (due to radiation dosage) as low as $6.3X10^3$ rads (Si) were reported for some MOS devices. Consequently, one must conclude that Metal-Oxide Field-Effect Transistors (MOSFETs) exhibit low radiation resistance and must be considered on a case-by-case basis for any gamma dose of greater than 10^3 rads. The unijunction transistor does depend on the minority-carrier lifetime, and hence will degrade at approximately the same rate as general silicon bipolar transistors. (1)P142.

5.4.4 <u>Integrated Circuits</u> - One can expect integrated circuits to be as radiation resistant as the same circuit made up with comparable discrete components. (1)p142. In accordance with this reasoning, and in accordance with the above discussions on resistors, capacitors, diodes, and transistors, one can conclude that integrated circuits (ICs) can tolerate a gamma dose of $1X10^5$ rads and perform satisfactorily, with an exception. The exception is metal-oxide-semiconductor technology. ICs with this technolgoy (such as NMOS, PMOS, CMOS, etc.) must be evaluated on a case-by-case basis for any gamma dose greater than 10^3 rads.

5.5 Radiation Effects on Insulation and Insulators

Insulation and insulators play a major role in electrical equipment, and can be classified as organic and inorganic. Reference 4 reports on radiation effects on elastomeric and plastic components. Reference 1 addresses both organic and inorganic insulation and insulators. However, references 2, 5, and 6 are much later in date and will be principally used to establish a lower threshold gamma dose.

5.5.1 **Inorganic Insulation and Insulators** - The following quote is from page S-1 of reference 2: "With certain very notable exceptions, inorganics/metallics are much less susceptible to radiation damage than organic." Reference 2, pages 2-1 and 2-2, goes on to point out that these "very notable exceptions are some semiconductors and the optical properties of glasses." The optical properties of glasses have been briefly discussed in subsection 5.3.3 and semiconductors in subsection 5.4. The conclusion was that neither of these categories of materials will prohibit the establishment of an integrated gamma radiation dose of 1X10^5 rads as a guideline value for an "essentially mild" environment except PIN diodes and MOS devices. Since the remainder of the inorganic/metallic class of materials can tolerate radiation better than organic materials, attention is now turned to organic insulators.

5.5.2 **Organic Insulation and Insulators** - The following excerpt is taken from page S-2 of reference 2:

> Information presented in this report concerning organic materials used in plant equipment suggests an exclusion from test or further analysis should be allowed for nonelectronic equipment subjected to 10^4 rads or less. Nonelectronic equipment which contains no teflon and is subjected to less than 10^5 rads should likewise be excluded. At these levels there is no significant degradation of mechanical or permanent electrical properties of the listed materials.

The excerpt below was taken from page 4-1 of reference 5:

> This study confirms the results from the previous investigation (1) in that virtually all the materials have thresholds above 10^5 rads. Only one of the synthetic organics was found to have a radiation degradation threshold consistently below 10^5 rads but above 10^4 rads, namely flurocarbons.

The "previous investigation (1)" referred to in the above excerpt is EPRI NP-2129, i.e., reference 2 in this calculation. Based on the above, one can conclude that insulation and insulators can tolerate an integrated gamma dose of $1X10^5$ rads without significant adverse effects, except fluorocarbons: fluorocarbons can tolerate a gamma dose above 10^4 rads but below 10^5.

5.6 Radiation Effects on Magnetic Materials

Based on a review of radiation effects on magnetic materials reported in pages 171-180 of reference 1, the conclusion is that the magnetic materials typically used in electrical equipment can tolerate an integrated gamma dose of at least $1X10^5$ rads and not suffer significant degradation.

5.7 Radiation Effects on Transformers

The most prevalent problem with respect to the irradiation of transformers has been deterioration of the insulating materials, particularly on the lead wires, but also on the windings. A second problem has been the expansion and breaking down of the potting material. Data reported in reference 1, pages 181-187 indicate that transformers will function well electrically to integrated gamma doses of $1X10^7$ rads and beyond, depending primarily on insulation and potting. Fluorocarbons are excluded for insulation or potting.

5.8 Radiation Effects on Printed Circuit Boards (PCBs)

Reference 1 (page 193) reports one experiment in which a G-10 fiberglass epoxy PCB was said to have slight volumetric changes at an exposure of $1X10^8$ rads gamma. Table 35 (page 194) in reference 1 summarizes radiation effects on various printed circuit boards with various coatings. Printed circuit boards were used extensively in the radiation experimental work reported in reference 6. For example consider test procedure No. 65305-05-02, section 6, of reference 6, where a radiation exposure of $1X10^6$ rads (gamma) for the PCBs is required. The following excerpt is from page S-3 of reference 6:

> Upon completion of the main tests described above, supplementary tests were performed to examine the effects of radiation aging on the seismic performance of the components. About half the population of specimens were subjected to radiation doses of 10^5 to 10^6 rads, representing typical conservative doses in mild plant environments. The results were the same--except for relays, all components with or without radiation aging functioned during and after severe seismic tests,

The "main tests" in the first sentence of the excerpt above refer to seismic tests on thermally and cyclically aged components and unaged components to determine any correlation.

Reference 9 (see Table 1 in subsection 5.1.3 above) indicates that PCBs were irradiated with total doses as high as 1X10^6 rads (gamma) without failure. Reference 17 reports on the effects of ionizing radiation on the copperclad polyimide interconnection systems. Copperclad polyimide is used as flexible PCBs. The following statement is from page 1345 of reference 17: "Copperclad polyimide is a radiation-tolerant material suitable for use in flexible circuit applications and beam-tape assembled semiconductor devices. These radiation tests have demonstrated the feasibility to function properly and survive exposure to 3.8X10^8 rads (Si)."

Based upon the above information, it is concluded that PCBs, excluding fluorocarbons from their construction, can tolerate at least a 1X10^5 rads (gamma) radiation dose without significant degradation.

5.10 Radiation Effects on Relays and Switches

Nuclear radiation affects relays and switches primarily by damage to the organic insulation and construction materials. Typical behavior of relays and switches in a radiation environment is shown in Table 36 (pages 196-199) in reference 1.

A review of Table 36 indicates that, for all entries where gamma radiation data is given, the total dose exceeded 1X10^5 rads except for one, i.e., 8.8X10^4 rads for the Leach Corporation type 9410, LMSC1060603-1 (found on page 198 of reference 1). The statement was made in the table (concerning this entry) that the device worked satisfactorily at least up to 8.8X10^4 rads. The indication is that the device was not tested beyond 8.8X10^4 rads. Consequently, Table 36 contains no evidence of relay or switch malfunction for gamma doses of 1X10^5 rads or less.

Reference 3, page 661, indicates that some micro-switches suffer damage to the plastic cases and actuators at gamma-ray exposures as low as 4 to 6X10^6 rads (C) or integrated neutron fluxes at 10^{15} n cm^{-2}.

Reference 9 (see Table 1 in subsection 5.1.3 above) reports both panel-mounted and PCB-mounted relays exposed to a radiation dose as high as 1X10^6 rads (gamma) without failure.

Based upon the above information, it is concluded that relays and switches, if fluorocarbons are excluded from their construction, can withstand a total radiation dose of $1X10^5$ rads (gamma) with no significant deterioration in their characteristics.

5.10 Radiation Effects on Electrical Connectors, Including Terminal Blocks

Because metals are known to undergo relatively small changes in electrical characteristic when exposed to nuclear radiation, there is little concern about radiation effects on the metal parts of the connectors. The main concern is the dielectric and the effects of radiation on it. Connectors containing ceramic inserts are least susceptible to radiation damage, with threshold values for gamma radiation of $6X10^9$ rads. Connectors containing organic insulation are more susceptible as indicated by their functional threshold values of $4X10^4$ rads for Teflon to $5X10^9$ rads for polystyrene. (1) p202. In accordance with a review of radiation effects on insulation materials (used in electrical connectors) as reported in references 1 through 6, and excluding fluorocarbons, it is concluded that electrical connectors and terminal blocks can absorb a gamma radiation dose of $1X10^5$ rads or less without significant degradation.

5.11 Radiation Effects on Electrical Meters

In general, the effects of nuclear radiation on meters have not been studied specifically to the depth that various components (such as magnetic materials, insulation, limiting and dropping resistors, rectifiers, magnet coils, structural members, etc.) have been studied. One can combine and utilize the component data in such a way as to reach reasonable expectations about the extent of damage that might be encountered when meters of various types are exposed to nuclear radiation. Materials typically used for construction of meter cases are usually metal and/or plastic. Metals are generally brass, aluminum, or steel. The two principal areas of concern involving meter cases are visual darkening of the glass, and the rupture of moisture-proofing seals between the glass window and the metal and/or plastic case. Another area of concern exists with respect to radiation effects on materials used within the sealed meter case. If the insulation materials (interior to the case) outgas upon irradiation, internal pressures might rupture seals. Reference 1 (pages 204-206)and reference 3 (pages 651-654) each contain a section on radiation effects on electrical meters. A review of these sections, along with component data in references 2 through 5, indicates that, if fluorocarbons (which are the only organic materials typically used in instrument construction and which have radiation tolerance levels below $1X10^5$ rads) are excepted, electrical meters will function properly with a gamma dose of $1X10^5$ rads or less.

5.12 Radiation Effects on Piezoelectric Crystals

Reference 1 (pages 188-190) has a section on radiation effects on piezoelectric crystals. Hundreds of different types of crystals are known, and a majority of these possess piezoelectric response. The most popular material used in practical applications is quartz since it is suitable for precise control of frequency in transmitting, monitoring and receiving circuits, and in production of highly selective circuits. One of the most common applications for crystals possessing piezoelectric characteristics is in transducers or accelerometers. (1)p188. Reference 3 (page 646) discusses a comprehensive study of radiation effects on crystals by manufacture and type number made by Pfaff and Shelton (in 1958). The total integrated fast neutron flux for various crystal units varied from $2X10^{13}$ n cm^{-2} to $9X10^{13}$ n cm^{-2}. The gamma dose rate was $5.6X10^5$ rads (C) per second, but the total dose was not stated. Of the 154 units tested and exposed to nuclear radiation, 54 per cent were classified as failures. When 41 crystal units were irradiated in a gamma-ray environment (without neutron bombardment), only one crystal unit was observed to fail. This situation appears to imply that the bulk of the 54% failure rate (when both neutron flux exposure and gamma-ray exposure were present) was due to neutron flux exposure. In this calculation, the "mild" environment includes gamma ray exposure and excludes (because of location of instruments,etc.) neutron flux exposure.

Reference 15 reports (among other items) testing two sync generator circuits which were irradiated with a total gamma dose of greater than $2X10^8$ rads (Si). Among the electronic components in the sync generator was a 2 MHz quartz crystal. The quartz crystals used in the tested sync generators were synthetic swept, AT cut, -55°C to +125°C, "off the shelf" components. The two sync generators functioned properly and were very frequency stable throughout the radiation exposures to greater than $2.1X10^8$ rads(Si). Reference 15 states that this was the first fully monitored Co-60 testing of quartz crystal generated frequencies to this total dose level.

The Valve Flow Monitoring System furnished to TVA by Technology for Energy Corporation (TEC) on contract 80K62-827118 contains an accelerometer with a piezoelectric crystal in it. The equipment was irradiated with gamma rays to a total of $2.22X10^8$ rads and still functioned properly. This is documented in TEC qualification test report No. 517-TR-03, Rev. 2 dated December 1981, furnished on the contract.

Based upon a review of the information presented in references 1,3, and 15, and the information immediately above, it is concluded that piezoelectric crystals will tolerate a total radiation dose of at least $1X10^5$ rads without significant degradation of the crystal characteristics.

6.0 COMMENTS ON CLASSES OF COMPONENTS OR MATERIALS

Section 5 of this calculation, as part of the argument that a radiation environment producing an integrated gamma dose of 510^4 rads or less may be considered "essentially mild," presented comments on specific components. This section will present comments on classes or groups of components or materials as a companion part of that argument.

6.1 Comments Based on Reference 2 - The project objective of the work reported in reference 2 is defined in the following excerpt taken from page iii of reference 2:

> The main objective of this project was to determine, to the extent possible, a low-level threshold dose for radiation damage to organic materials in plant equipment. Equipment located in a benign plant environment and exposed to less than the threshold dose during its design life could be excluded from the general qualification requirement for radiation testing or further analysis of radiation effects. The information compiled can also assist in the design and qualification of equipment subjected to high-level radiation doses.

The project results of reference 2 are given in the following excerpt, also from page iii of reference 2:

> The report includes an overview of radiation effects and an extensive list of organic materials in order of increasing resistance to radiation damage. An important finding is that a total dose of less than 10^5 rads produces no significant degradaton of mechanical or electrical properties. (Notable exceptions are equipment that contain Teflon or semiconductor devices). Also, at this level, no significant synergistic effects of radiation combined with other environmental stresses, such as elevated temperatures, were identified. The results of this work will be of interest to utility engineers, architect-engineers, equipment manufacturers, and regulatory staff involved in the qualification of equipment for radiation effects.

The "notable exceptions," i.e., semiconductors and teflon, have been addressed at various times in section 5 of this calculation. If one excludes metal-oxide-semiconductor technology, PIN diodes, and fluorocarbons (such as teflon), then reference 2 supports the argument that a total radiation dose of less than1X10^5 rads will produce no significant adverse effects on other materials covered in the study. As indicated in the following quote from the abstract on page V of reference 2, inorganics and metallics were considered as well as organic materials: "Inorganics and metallics are considered briefly. With a few noted exceptions, these are more radiation resistant than organic materials."

6.2 Comments Based on Reference 5

Reference 5 reports data summarizing the responses to ionizing radiation of five categories of synthetic organic materials: insulators, elastomers, lubricants, adhesives, and coatings. With respect to the scope of this calculation, the following excerpt from page 4-1 of reference 5 gives the gist of the report:

> This study confirms the results from the previous investigation in that virtually all of the materials have thresholds above 10^5 rads. Only one of the synthetic organics was found to have a radiation degradation threshold consistently below 10^5 rads but above 10^4 rads, namely fluorocarbons. Although some investigators found thresholds for nylons and epoxy resins in the same range, the lower thresholds were in the minority with respect to other published data on these materials. Nonetheless, caution is advised if these latter polymers are selected for use. Two additional materials, polyethylene oxides and poly-alpa-methyl chloroacrylates, were found to have thresholds below 10^5 rads, but their properties improved rather than degraded with increasing dose for approximately two orders of magnitude above 10^5 rads.

The "previous investigation (1)" in the excerpt above refers to EPRI NP-2129 which is reference 2 in this calculation.

6.3 Comments Based on Reference 6

Reference 6 reports, as a supplement to main tests involving thermal and cyclic aging, data from radiation aging of the following types of components: resistors, capacitors, transistors, diodes, integrated circuits, relays, and terminal blocks. The following is an excert from page S-3 of reference 6:

> Upon completion of the main tests described above, supplementary tests were performed to examine the effects of radiation aging on the seismic performance of the components. About half the population of specimens were subjected to radiation doses of 10^5 to 10^6 rads, representing typical conservative doses in mild plant environments. The results were the same--except for relays, all components with or without radiation aging functioned during and after severe seismic tests, whereas irradiated relays showed signs of diminished seismic performance. Therefore, the conclusions reached above for the main test series are reinforced and extended to include radiation aging as well as thermal and cycle aging.

The components reported in reference 6 were energized and tested (such as a 5V ± 5% input square wave to the semiconductors while output was monitored) before, during, and after irradiation, and before, during, and after seismic excitation (which followed the irradiation). One should note from the above excerpt that all the components functioned satisfactorily after a radiation dose of 10^5 to 10^6 rads except relays which showed signs of diminished seismic performance. Relays have been discussed with respect to irradiation and the effects on its electrical characteristics (without regard to seismic excitation) in subsection 5.9 above. Also, seismic events are outside the scope of 10CFR50.49.

6.4 Comments Based on Test Reports for TVA Equipment

Exhibit D-1 below is a tabulation of a number of test reports provided with equipment furnished by various manufacturers to TVA. Each instrument reported upon contained an electronic assembly which could reasonably be termed typical. However, one must remember that these electronic assemblies were built with the conscious intent of being exposed to the reported radiation environment. Even so, the data adds credence to the "essentially mild" argument.

EXHIBIT D-1
SUMMARY OF QUALIFIED RADIATION LEVELS ON A NUMBER OF INSTRUMENTS CONTAINING ELECTRONIC ASSEMBLIES

Manufacturer	Report No.	Report Pages	Test Radiation Level
1. Gould	1006	43-45	5.5×10^7*
2. Barton 764 Lot 4&7	WCAP-8687 EQTR-E03A	15	6.8×10^7
3. Barton 763	WCAP-8687 EQTR-E03A	16	6.8×10^7
4. FCI Model 12-64 & FR72	708053	App E-98&99 Addenda A&B	5×10^6 (Electronic)
5. Namco	QTR105R3	11-21, 10-7	2.04×10^8

The radiation level to which the equipment is qualified is temperature dependent, i.e., the equipment is qualified to:

5.5×10^6 rads for $T > 140°$

5.7×10^7 rads for $T < 140°$

where T = temperature

7.0 CONCLUSIONS

Based upon the comments presented above in sections 5 and 6, the following conclusions are made with respect to the equipment within the scope of interest (as defined in section 4 above):

a. Electronic components, typical for each class of components and commercially available without special manufacture or selection, will (with the exceptions defined in b. below) tolerate a total radiation dose (total 40 years integrated dose plus accident dose) of $5X10^4$ rads or less and continue to function without significant degradation.

b. Exceptions to a. above are:

(1) metal-oxide-semiconductor (MOS) technology (such as MOSFETs, NMOS, PMOS, CMOS, etc.);

(2) fluorocarbons

(3) PIN diodes

c. The electronic components mentioned in a. above are in a mild environment (with respect to radiation as defined in 10CFR50.49c).

Note that the $5X10^4$ rads total radiation dose given in a. above has a degree of conservatism in it. Arguments have consistently been made for $1X10^5$ rads throughout sections 5 and 6 above. With respect to the exceptions in b. above, each situation involving these components and/or materials must be reviewed on a case-by-case basis. Any application using MOS technology at radiation levels above 10^3 rads should be reviewed for shielding, etc. PIN diodes are typically used in microwave applications (such as limiters, etc.), and are not generally a concern in nuclear power plants.

8.0 REFERENCES

1. Radiation Effects Information Center (REIC) Report No. 36, "The Effect of Nuclear Radiation on Electronic Components, Including Semiconductors," October 1, 1964. (B70 851213 101).

2. Electric Power Research Institute (EPRI) NP-2129, "Radiation Effects on Organic Materials in Nuclear Plants," November 1981. (B70 851030 101)

Computed By RDM
Date 9-12-86

Checked by ajB
Date 9-12-86

3. Effects of Radiation on Materials and Components, by John F. Kircher and Richard F. Bowman, Reinhold Publishing Corporation, New York, New York, 1964.

4. REIC Report No. 21, "The Effect of Nuclear Radiation on Elastomeric and Plastic Components and Materials, "September 1, 1961. (B70 851209 116)

5. EPRI NP-4172M, "Radiation Data for Design and Qualification of Nuclear Plant Equipment," August 1985. (B70 851030 100)

6. EPRI NP-3326, "Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components," December 1983. (B70 851213 100)

7. Johnson, R. T., Jr., Thome, F.V. and Craft, C.M., "A Survey of Aging of Electronics with Application to Nuclear Power Plant Instrumentation," IEEE Transactions on Nuclear Science, Vol. NS-30, No. 6, December 1983.

8. Johnson, R. T., Jr., Thome, F. V., and Craft, C. M., "Aging of Electronics with Application to Nuclear Power Plant Instrumentation, "IEEE Transactions on Nuclear Science, Vol. NS-31, No. 1, February 1984.

9. Gleason, James F., "Aging and Seismic Performance for Safety-related Equipment in A Mild Environment," IEEE Transactions on Nuclear Science, Vol. NS-31, No. 1, February 1984.

10. Binkley, David M., "A Low-Cost Radiation-Hardened Preamplifier for Piezoelectric Accelerometers in Nuclear Power Plants," IEEE Transactions on Nuclear Science, Vol. NS-29, No. 6, December 1982.

11. EPRI NP-4172SP, "Radiation Data for Design and Qualification of Nuclear Plant Equipment," August 1985.

12. Nuclear Radiation Detection, by William J. Price, McGraw-Hill Book Co., New York, New York, 1964

13. Transistor, Thyristor and Diode Manual, Radio Corporation of America (RCA), Harrison, New Jersey 1969

14. SCR Manual, Sixth Edition, General Electric Semiconductor Products Department, published by Prentice-Hall, Inc., Englewood Cliffs, NJ, 1982

15. Meyers, D. K. and Herzog, Williams, "Feasibility Study on the Design and Radiation Testing of Complex Functions for $2X10^8$ (Si),"IEEE Transactions on Nuclear Science, Vol. NS-29, No. 6, December 1982.

16. Measel, P. R., Greegor, R. B., and Wahlin, K. L., "Radiation Response of Several Memory Device Types," IEEE Transactions on Nuclear Science, Vol. NS-27, No. 6, December 1980.

17. Myers, D. K., Herzog, W., Phy, W., and Coppage, F., "Ionizing Radiation Effects on Copperclad Polyimide," IEEE Transactions on Nuclear Science, Vol. NS-31, No. 6 December 1984.

DNE1 - 0302W

Attachment 3

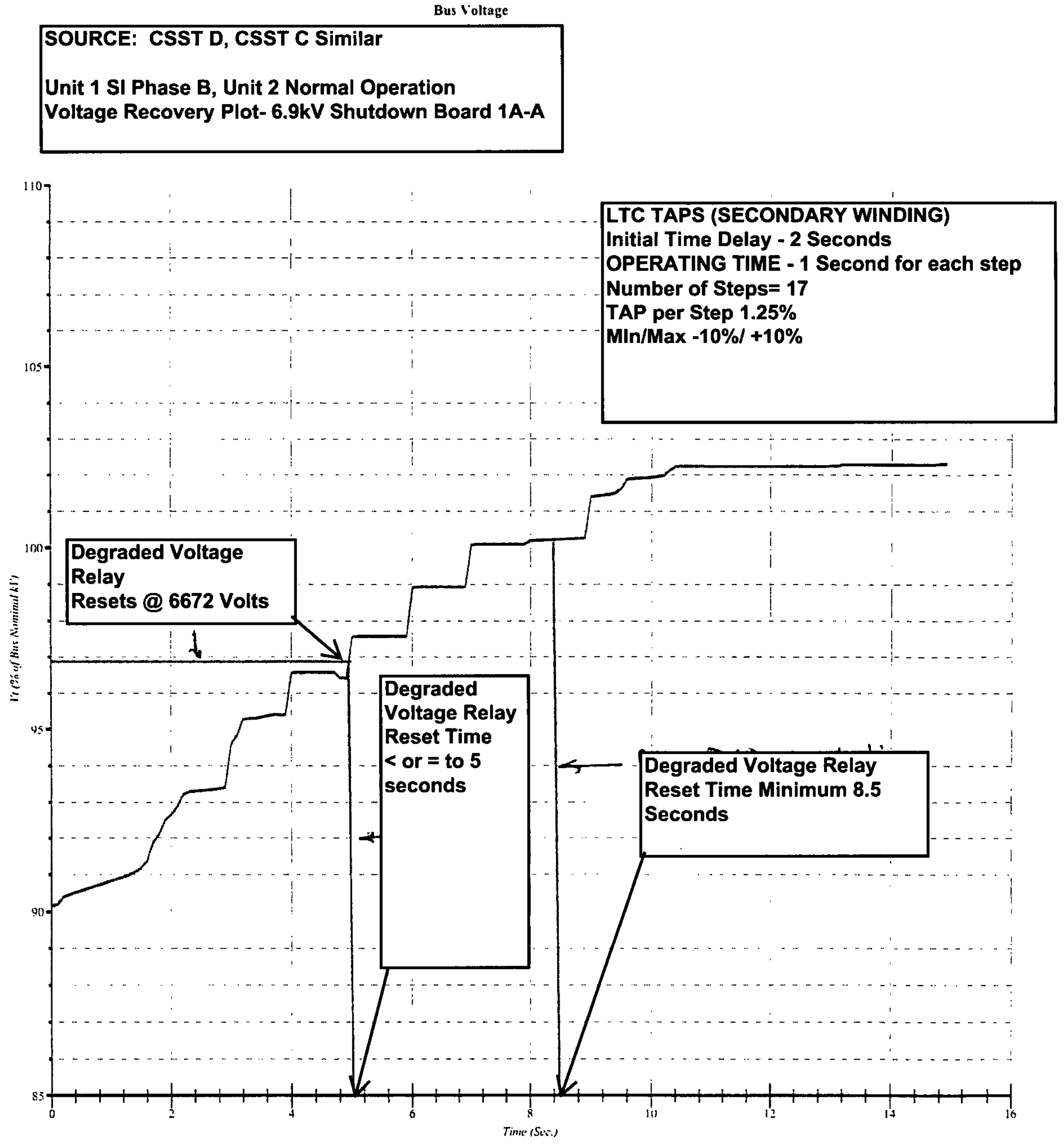
Electrical Transient Analysis Program (ETAP) Voltage Recovery Plots

```
Project:     Watts Bar Nuclear Plant                        ETAP                              Date:       05-14-2008
Location:    //chachaapp5/etaps/wbnp/                       5.5.6N                            SN:         90TVP12DC2
Contract:                                                                                     Revision:   Unit 1&2
Engineer:                                                   Study Case: U1 SIB AD-U2          Config.:    SH CSSTAD-U2
```

```
WBN-EEB-EDQ000-999-2007-0002, R0
Unit 1 SI Phase B.  Grid drop 164-153kV.  Shutdown on  CSST A&D.  U1 DBE U2 NorOps.
```

```
Project File:  J:\wbnp\WBNDATA
Output Report: U1SIB-AD-U2
```

MOTOR STARTING ANALYSIS



SOURCE: CSST D, CSST C Similar

Unit 1 SI Phase B, Unit 2 Normal Operation
Voltage Recovery Plot- 6.9kV Shutdown Board 1A-A

LTC TAPS (SECONDARY WINDING)
Initial Time Delay - 2 Seconds
OPERATING TIME - 1 Second for each step
Number of Steps= 17
TAP per Step 1.25%
MIn/Max -10%/ +10%

Degraded Voltage Relay
Resets @ 6672 Volts

Degraded Voltage Relay Reset Time < or = to 5 seconds

Degraded Voltage Relay Reset Time Minimum 8.5 Seconds

Project: Watts Bar Nuclear Plant
Location: //chachaapp5/etaps/wbnp/
Contract:
Engineer:

ETAP
5.5.6N

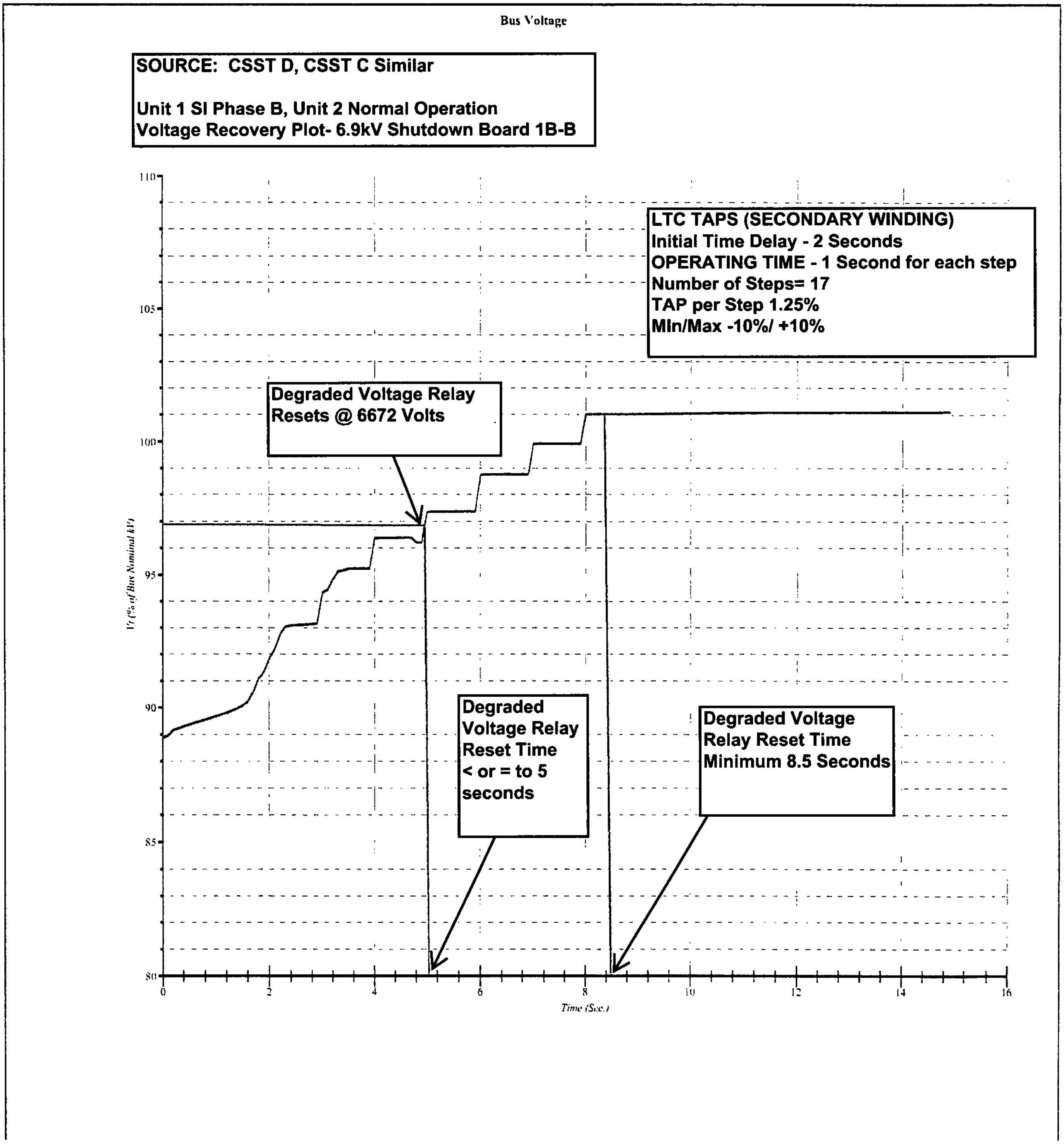
Study Case: U1 SIB AD-U2

Date: 05-18-2006
SN: 90TVA12DC2
Revision: Unit 1&2
Config.: SH CSSTAD-U2

WBN-EEB-EDQ000-999-2007-0002, R0
Unit 1 SI Phase B. Grid drop 164-153kV. Shutdown on CSST A&D. U1 DBE U2 NorOps.

Project File: J:\wbnp\WBNDATA
Output Report: U1SIB-AD-U2

MOTOR STARTING ANALYSIS



SOURCE: CSST D, CSST C Similar

Unit 1 SI Phase B, Unit 2 Normal Operation
Voltage Recovery Plot- 6.9kV Shutdown Board 1B-B

LTC TAPS (SECONDARY WINDING)
Initial Time Delay - 2 Seconds
OPERATING TIME - 1 Second for each step
Number of Steps= 17
TAP per Step 1.25%
MIn/Max -10%/ +10%

Degraded Voltage Relay Resets @ 6672 Volts

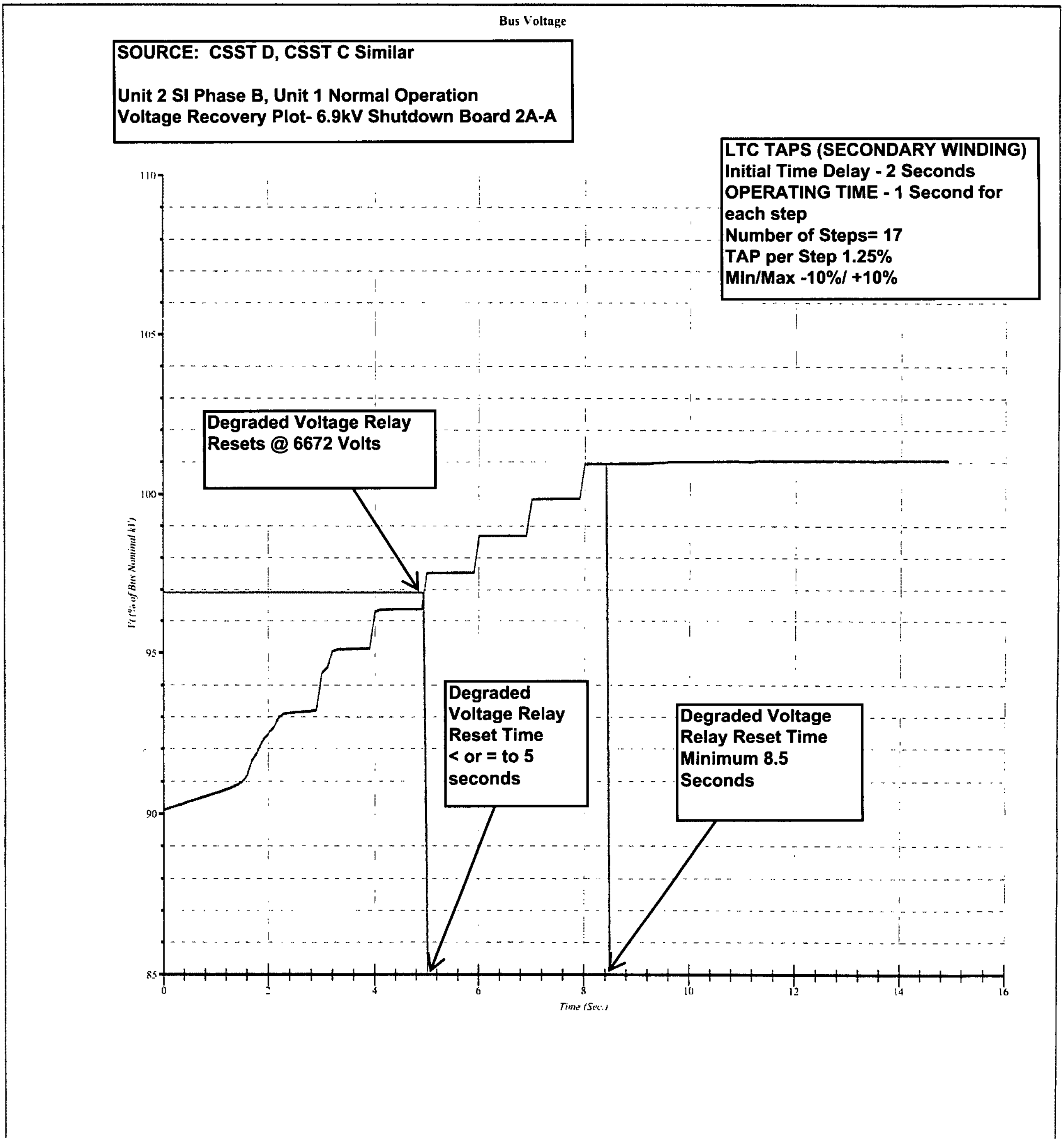
Degraded Voltage Relay Reset Time < or = to 5 seconds

Degraded Voltage Relay Reset Time Minimum 8.5 Seconds

WBN-EEB-EDQ000-999-2007-0001, R0
Unit 2 SI Phase B. Grid drop 164-153kV. Shutdown on CSST A&D. U2 DBE U1 NorOps.

Project File: J:\wbnp\WBNDATA
Output Report: U2SIB-AD-U2

MOTOR STARTING ANALYSIS



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Location:    //chachaapp5/etaps/wbnp/                                                                           SN:         90TVA12DC2
Contract:                                                                                                       Revision:   Unit 1&2
Engineer:                                                              Study Case: U2 SIB AD-U2                 Config.:    SH CSSTAD-U2
```

```
WBN-EEB-EDQ000-999-2007-0002, R0
Unit 2 SI Phase B.  Grid drop 164-153kV.  Shutdown on  CSST A&D.  U2 DBE U1 NorOps.
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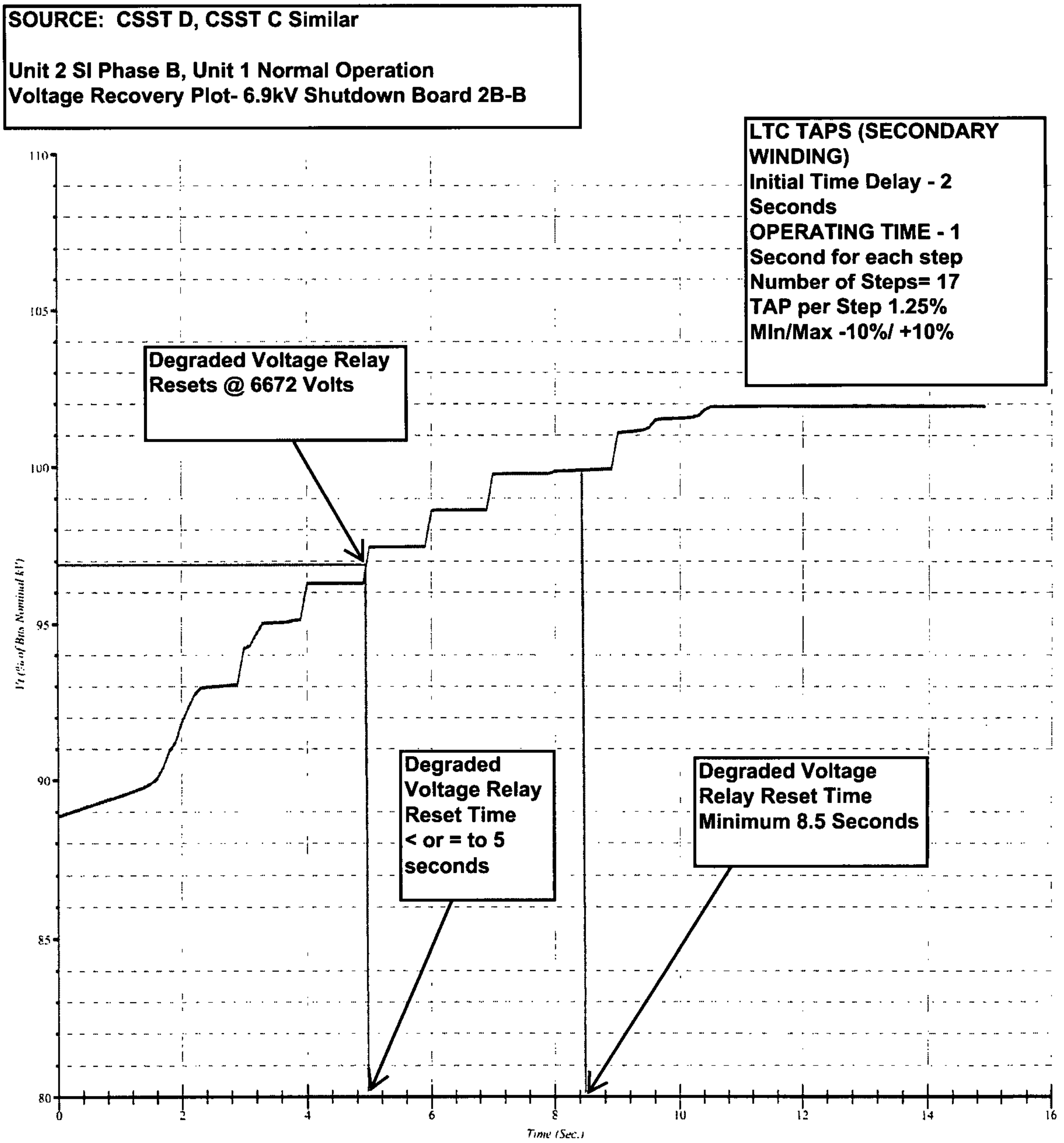
Project File:  J:\wbnp\WBNDATA
Output Report: U2SIB-AD-U2
```

MOTOR STARTING ANALYSIS

Bus Voltage



SOURCE: CSST D, CSST C Similar

Unit 2 SI Phase B, Unit 1 Normal Operation
Voltage Recovery Plot- 6.9kV Shutdown Board 2B-B

LTC TAPS (SECONDARY WINDING)
Initial Time Delay - 2 Seconds
OPERATING TIME - 1 Second for each step
Number of Steps= 17
TAP per Step 1.25%
MIn/Max -10%/ +10%

Degraded Voltage Relay Resets @ 6672 Volts

Degraded Voltage Relay Reset Time < or = to 5 seconds

Degraded Voltage Relay Reset Time Minimum 8.5 Seconds

ETAP
5.5.6N

Project: Watts Bar Nuclear Plant
Location: //chachaapp5/etaps/wbnp/
Contract:
Engineer:

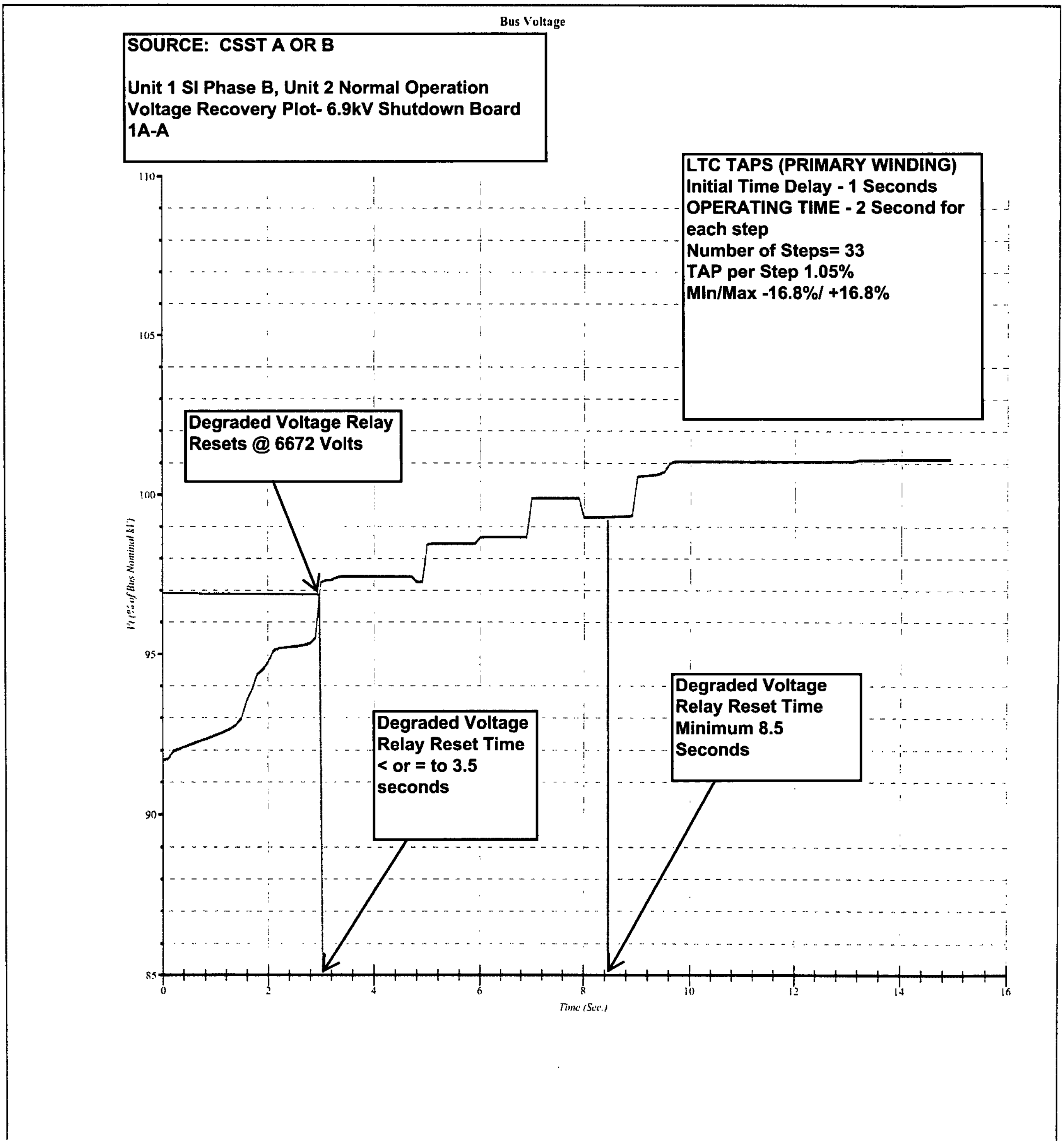
Study Case: U1 SIB AB-U2

Date: 05-11-2009
SN: 90TVA12DC2
Revision: Unit 1&2
Config.: SH C/SAB1-U2

WBN-EEB-EDQ000-999-2007-0002, R0
Unit 1 SI Phase B. Grid drop 162-153kV. Shutdown on CSST A&B. DBE U1 on CSST, U2 on USST, CSST C&D oos.

Project File: J:\wbnp\WBNDATA
Output Report: U1SIB-AB9KVD-U2

MOTOR STARTING ANALYSIS



Project: Watts Bar Nuclear Plant
Location: //chachaapp5/etaps/wbnp/
Contract:
Engineer:

ETAP
5.5.6N

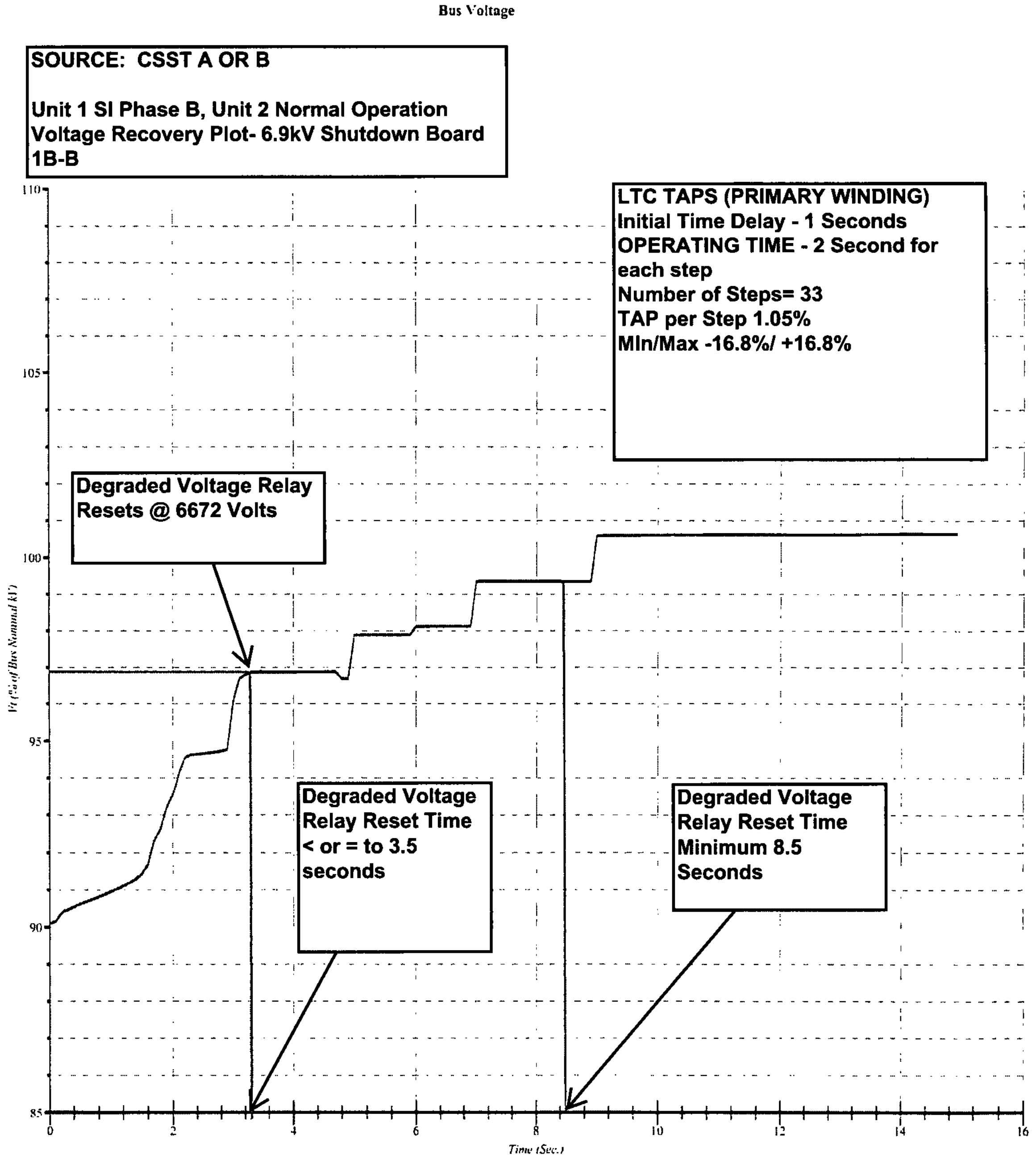
Study Case: U1 SIB AB-U2

Date: 05-12-2008
SN: 9CTVP12DC2
Revision: Unit 1&2
Config.: SH CSSAB1-U2

WBN-EEB-EDQ000-999-2007-0002, R0
Unit 1 SI Phase B. Grid drop 162-153kV. Shutdown on CSST A&B. DBE U1 on CSST, U2 on USST, CSST C&D pos.

Project File: J:\wbnp\WBNDATA
Output Report: U1SIB-AB9KVD-U2

MOTOR STARTING ANALYSIS



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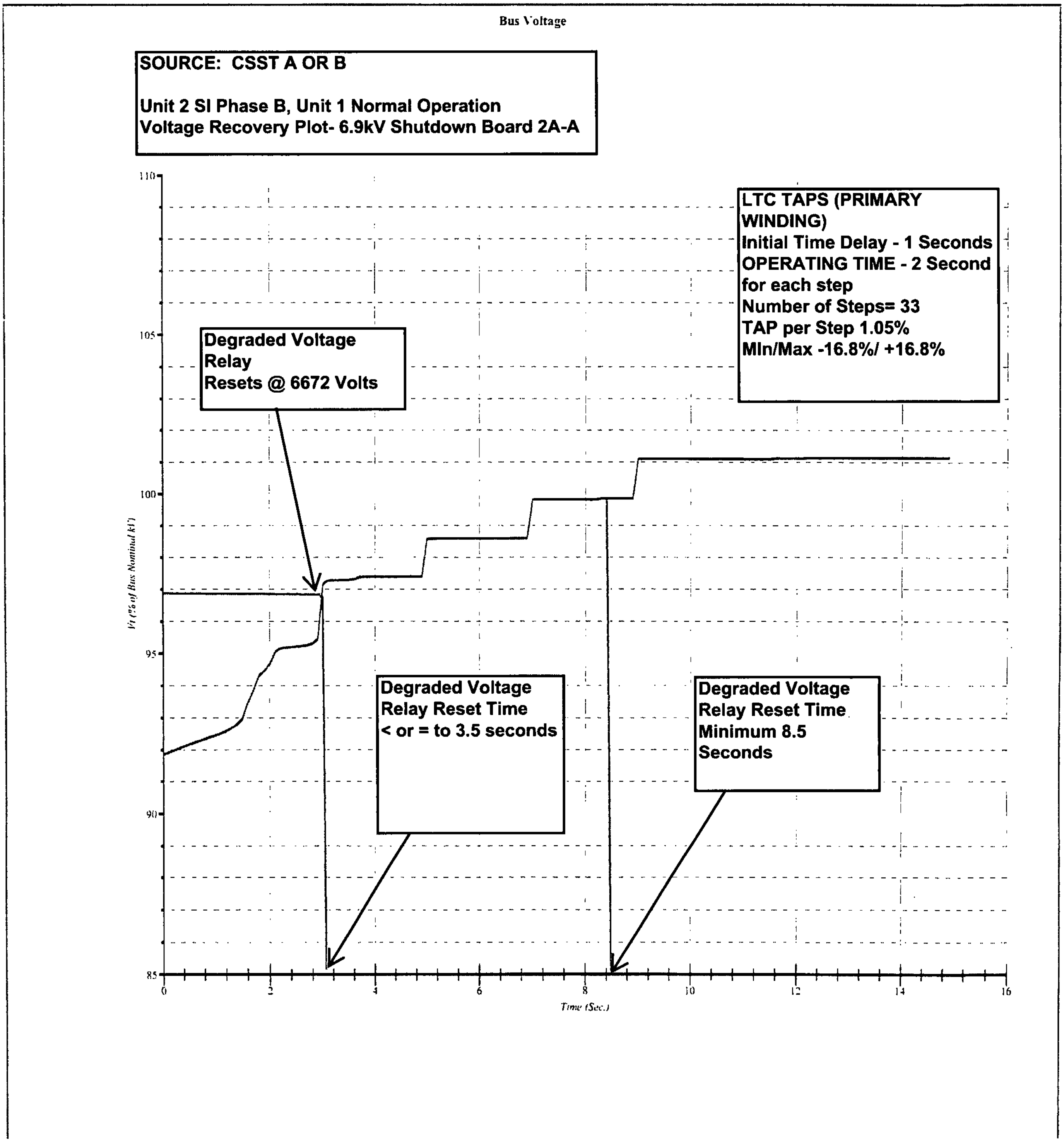
WBN-EEB-EDQ000-999-2007-0002, R0
Unit 2 SI Phase B.  Grid drop 162-153kV.  Shutdown on  CSST A&B.  DBE U1 on CSST, U2 on USST, CSST C&D oos.


Project File:  J:\wbnp\WBNDATA
Output Report: U2SIB-AB9KVD-U2
```

MOTOR STARTING ANALYSIS



SOURCE: CSST A OR B

Unit 2 SI Phase B, Unit 1 Normal Operation
Voltage Recovery Plot- 6.9kV Shutdown Board 2A-A

LTC TAPS (PRIMARY WINDING)
Initial Time Delay - 1 Seconds
OPERATING TIME - 2 Second for each step
Number of Steps= 33
TAP per Step 1.05%
MIn/Max -16.8%/ +16.8%

Degraded Voltage Relay
Resets @ 6672 Volts

Degraded Voltage Relay Reset Time
< or = to 3.5 seconds

Degraded Voltage Relay Reset Time
Minimum 8.5 Seconds

```
                                              ETAP
Project:     Watts Bar Nuclear Plant          5.5.6N                       Date:       05-21-2008
Location:    //chachaapp5/etaps/wbnp/                                      SN:         90TVA12DC2
Contract:                                                                  Revision:   Unit 1&2
Engineer:                                     Study Case: U2 SIB AB-U2     Config.:    SH CSSAB2-U2
```

```
WBN-EEB-EDQ000-999-2007-0002, R0
Unit 2 SI Phase B.  Grid drop 162-153kV.  Shutdown on  CSST A&B.  DBE U1 on CSST, U2 on USST, CSST C&D oos.

Project File:  J:\wbnp\WBNDATA
Output Report: U2SIB-AB9KVD-U2
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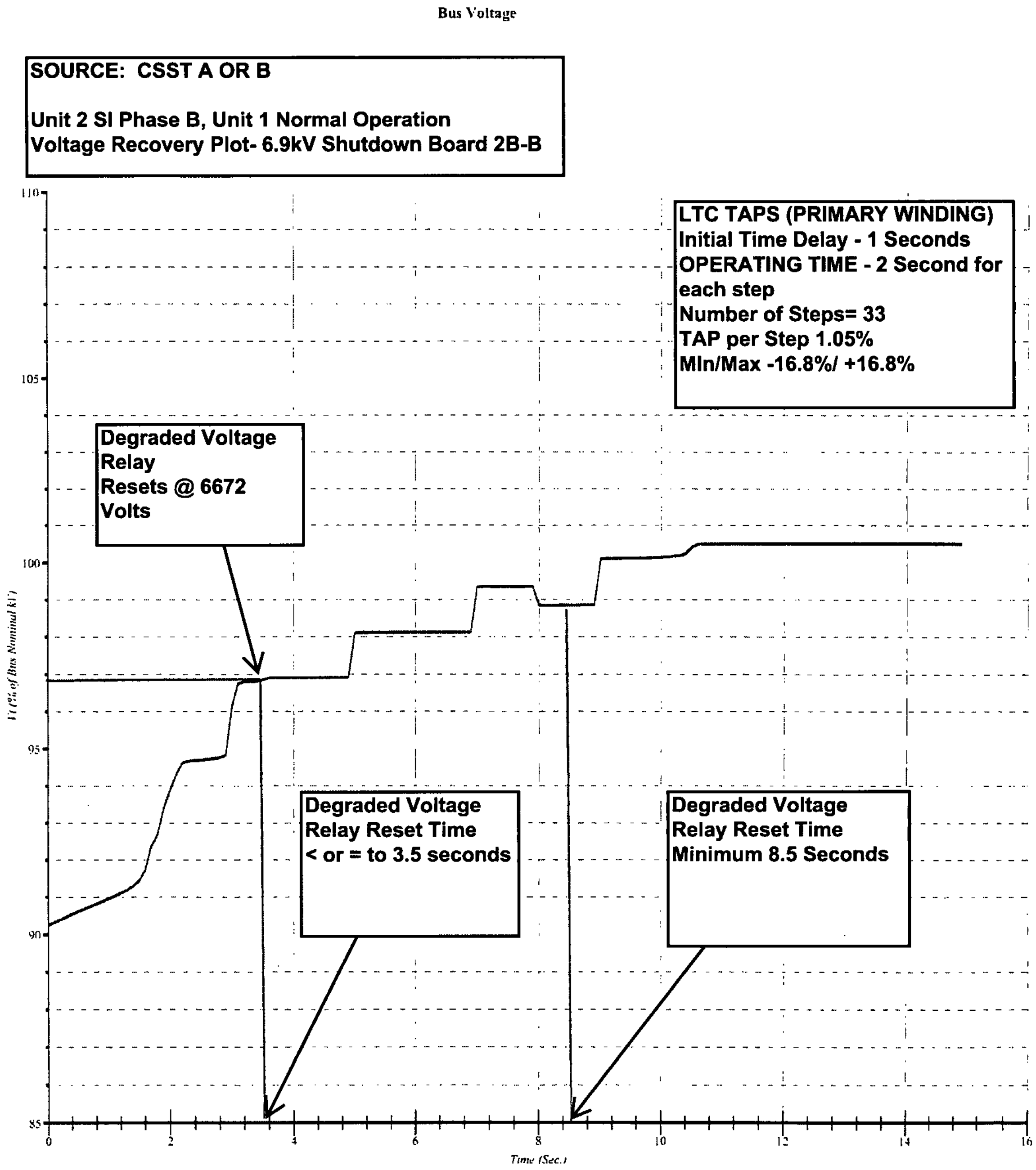
MOTOR STARTING ANALYSIS


Bus Voltage

SOURCE: CSST A OR B

Unit 2 SI Phase B, Unit 1 Normal Operation
Voltage Recovery Plot- 6.9kV Shutdown Board 2B-B

LTC TAPS (PRIMARY WINDING)
Initial Time Delay - 1 Seconds
OPERATING TIME - 2 Second for each step
Number of Steps= 33
TAP per Step 1.05%
MIn/Max -16.8%/ +16.8%

Degraded Voltage Relay Resets @ 6672 Volts

Degraded Voltage Relay Reset Time < or = to 3.5 seconds

Degraded Voltage Relay Reset Time Minimum 8.5 Seconds