Topical Report

Summary Evaluation of the TMI-1 Reactor Vessel Embrittlement for Operating Pressure/Temperature Limits

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Abstract:

The TMI-1 Technical Specification (T.S.), Section 3.1.2 provides operating pressure/temperature (P/T) limits for the prevention of brittle failure of the reactor vessel. These limits are presently applicable up to 10 EFPY. The end of the applicability period will be reached in September, 1993, commensurate with the TMI-1 10R refueling outage.

This report provides a summary of the evaluations of irradiated surveillance capsule data, which justify extension of the present P/T limits to an applicability period of 32 EFPY.

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1.0 <u>Introduction:</u>

The TMI-1 Technical Specification (T.S.), Section 3.1.2 provides operating limits for the prevention of brittle failure of the reactor vessel. These limits are termed as the pressure/temperature (P/T) limits and are presently applicable up to 10 EFPY. The end of the applicability period will be reached in September, 1993, commensurate with the TMI-1 10R refueling outage.

The purpose of this report is to provide a summary of the evaluations which justify extension of the present reactor vessel operating P/T limits beyond the 10 EFPY applicability period.

The operating P/T limits for the reactor vessel are calculated with linear-elastic fracture mechanics methods which are in compliance with 10CFR50, Appendix G and ASME Section III, Appendix G. Inputs to such calculations include the vessel geometry, operating heatup and cooldown rates, and the allowable material stress intensity. The allowable material stress intensity is provided by Appendix G of the Code and is a function of the metal temperature minus an indexing temperature called the reference nil-ductility temperature (RT_{NDT}). The RT_{NDT} is essentially a conservative value of the nil-ductility transition temperature (NDTT).

The initial RT_{NDT} is determined from the greater of the drop weight nil-ductility transition temperature (NDTT) or the temperature that is 60°F below that at which the Charpy tests of the material exhibits 50 Ft-Lbs and 35 mil lateral expansion. The irradiation induced changes, or shift trend, in the RT_{NDT} is defined to be equal to the shift in the 30 Ft-Lbs transition temperature (dRT_{NDT}).

Thus, the irradiated RT_{NDT} is an index of the state of radiation embrittlement of the material and is equal to the sum of the initial RT_{NDT} and the shift in the 30 Ft-Lbs transition temperature which is determined from Charpy test results. As a material is irradiated, its dRT_{NDT} increases by a trend which is a function of the applied cumulative fluence. Since the trend of irradiation damage is affected by factors such as the chemical impurities contained in the weld wire, correlations have been developed as a function of the amounts of these impurities in the weld metals. These correlation are presented in R.G. 1.99 Rev. 2 and have been termed as the chemistry factors as a function of the copper and nickel content. These chemistry factors are utilized to establish a trend in the vessel weld irradiation damage if irradiated surveillance capsule data is not available. The procedure by which this projection of trend is made is provided by position No. 1 of the regulatory guide. Position No. 2 provides for the use of irradiated surveillance capsules data of the weld material being evaluated to establish the trend of its irradiation damage.

The resulting trend of the irradiation embrittlement, whether determined by either position No. 1 or position No.2 of the regulatory guide, must be conservative and bound the irradiation damage which may be expected in the vessel weld materials.

The present 10 EFPY P/T limits were developed on the basis of RT_{NDT} values, for the controlling vessel beltline weld (SA-1526), which were based on overly conservative trends in the embrittlement per R.G. 1.99 Rev. 2, position No. 1.

This report provides the results of evaluations of the TMI-1 reactor vessel welds irradiation embrittlement trends on the basis of data from irradiated surveillance capsules which represent the weld metals contained in the TMI-1 reactor vessel.

The B&WOG Reactor Surveillance Program has irradiated many more surveillance capsules than had been anticipated by the authors of the regulatory guide. Thus, GPUN has assessed the surveillance capsule RT_{NDT} data as well as the procedure prescribed by position No. 2 of the R.G. and other methods which would provide bounding trends of the irradiation embrittlement of the vessel weld materials.

The evaluations have found that the trends in RT_{NDT}, of Linde-80 weld metals, which are based on regulatory guide position No. 1 are overly conservative. Use of position No. 2 does not provide a consistent trend of the data while other methods which have been evaluated seem to provide greater consistency. Such an alternate method has been applied to evaluate the TMI-1 reactor vessel welds irradiation embrittlement trends. These trends were then utilized to determine the EFPY at which the controlling or limiting weld metal would reach the RT_{NDT} value which was used as the input to the calculation of the 10 EFPY operating P/T limits contained in the TMI-1 Technical Specifications. The result is that the EFPY at which the RT_{NDT} of the limiting TMI-1 vessel weld will reach the input value for the 10 EFPY P/T limits is at 32.3 EFPY. Thus, the applicability of the present TMI-1 operating P/T limits could be extended to 32 EFPY without compromise of the measures for the prevention of brittle failure of the vessel.

While the RT_{NDT} of the material at the tip of the assumed 1/4 through wall thickness defect is used to generate operating P/T limits for the reactor vessel, other criteria such as the upper shelf energy (Cv-USE) of the material and the PTS Rule (10 CFR 50.61) must also be satisfied.

1.1 **PTS Rule (RT_{PTS}):**

The PTS Rule provides RT_{PTS} screening values to address the prevention of brittle failure of the vessel from potential RCS overcooling type transient in which the reactor could be repressurized while sustaining a state of high thermally induced stress from the overcooling. The projected RT_{PTS} of the weld metals if calculated in accordance with 10 CFR 50.61 yields virtually the same, but slightly different, value than the RT_{NDT} of the weld at the inside surface of the vessel.

The RT_{PTS} screening values are 270°F for longitudinal welds and 300°F for circumferential welds. Like the provisions in R.G. 1.99 Rev. 2, the PTS Rule (10 CFR 50.61, para. (b)(3)) permits the use of applicable surveillance capsule data for predicting a bounding trend in RT_{PTS}.

The previous estimates of the TMI-1 limiting weld RT_{PTS} value was based on use of calculative procedures assuming that irradiated surveillance capsules were not available. The resulting RT_{PTS} value was thus reported to be slightly less than the 270°F screening value for the limiting longitudinal weld (SA-1526) in the TMI-1 vessel.

The PTS Rule, as well as the TMI-1 Tech. Specs., require that an update of the calculated RT_{PTS} for the limiting vessel weld be provided whenever the Tech. Specs. regarding the operating P/T limits are revised. The resulting RT_{PTS} values for the TMI-1 reactor vessel, when calculated on the basis of irradiated surveillance capsules are significantly lower than had been previously reported. Since the RT_{NDT} at the inside surface of the vessel is virtually equal to the RT_{PTS} and the resulting value, based on capsule data, is significantly below the screening values, this report will consider them to be one and the same. Thus, the calculated maximum RT_{PTS} values for the TMI-1 vessel longitudinal weld SA-1526 and circumferential weld WF-25 are 217°F and 225°F respectively (App. A, Table No. 1).

1.2 <u>Upper Shelf Energy (C_v-USE):</u>

The upper shelf energy (C_v-USE) criteria requires that if the C_v-USE falls below 50 Ft-Lbs, then analysis must be provided to demonstrate the acceptability of operating below this value and the locations where this is expected to occur must be examined to establish the absence of unacceptable defects. This criteria has been established to ensure that at temperatures which are above the transition region from brittle to ductile, that the operating limits which are calculated on the basis of brittle fracture mechanics also provide adequate protection from ductile tearing during either normal operating conditions or design basis events.

In response to Generic Letter No. 92-01, the NRC was advised that some of the Linde-80 welds in the TMI-1 vessel are expected to fall below the 50 Ft-Lb screening criteria before the end of the plant license. The response also stated that these welds had been examined during the vessel 10 year ISI inspection and found no unacceptable defects. In regard to the required analysis, a plant specific analysis has not yet been performed, however, such analysis had been performed for the lead B&WOG plants and submitted to the NRC. The B&WOG also evaluated these analysis and determined that they bound the expected results of plant specific analysis, including the TMI-1 vessel. The B&WOG has also committed to the NRC that either plant specific or a bounding analysis for the remainder of the B&WOG vessels would be completed in 1993. Thus, while having no plant specific analysis for the TMI-1 vessel at the present time, the acceptability of TMI-1 to operate with C_v-USE values which are below 50 Ft-Lbs has virtually been demonstrated by the B&WOG activities and the results of the TMI-1 10 year ISI of the reactor vessel.

1.3 **Vessel Fluence:**

In addition to maintaining cognizance of the irradiated material behavior, the other component to protecting the reactor vessel from brittle fracture is maintaining low flux on the vessel surface. TMI-1 has long ago recognized this and has been proactive in continually reducing the vessel flux by prudent fuel management.

The reactor vessel fluence projections are tracked by a B&WOG activity. These projections are made on the basis of the average fluence which has been calculated in each of the previous two fuel cycles of operation. Since continuous efforts are made to reduce the applied fluence in future fuel cycles, the method of projecting the accumulated fluence at a future point in time is conservative.

In order to monitor the fluence which is actually being applied, TMI-1 has installed ex-vessel dosimetry. Both the B&WOG and GPUN are in the process of bench marking calculational methods which can be used to determine the applied fluence at the inside surface of the vessel from the ex-vessel dosimetry. Results of this activity are not yet available.

2.0 **Methods:**

The evaluation of the irradiation trend of the TMI-1 reactor vessel materials applied position No. 1 of the regulatory guide for the evaluation of the vessel plate materials and the provisions of position No. 2 for evaluation of the weld metals.

The plate metals are not as prone to irradiation damage as are the Linde-80 weld metals. There are also no irradiated surveillance capsule results which might be utilized per position No. 2 of R.G. 1.99 Rev. 2. Thus, the plate metals were evaluated in accordance with position No. 1 of the regulatory guide.

The Linde-80 weld metals which are in the TMI-1 reactor vessel and which are the most susceptible to irradiation damage have a large amount of irradiated surveillance capsules whose data can be evaluated. Thus, per the provisions of position No. 2 of the regulatory guide this data was evaluated to establish their irradiation embrittlement trends.

Once the irradiation embrittlement trends were defined, and the fluence at the weld locations were calculated, their RT_{NDT} values as a function of time, cycle number and EFPY were calculated. Then the fluence, time and EFPY at which weld SA-1526 reached the value which was used in the fracture mechanics analysis for the present operating P/T limits (186 deg.F) at the 1/4T location was determined. The RT_{NDT} values for the other beltline welds and peak fluence plate locations at that same point in time were then calculated.

2.1 <u>**Irradiated Surveillance Capsule Data Evaluation:**</u>

The B&WOG surveillance program contains irradiated capsules for three (3) of the five (5) weld wires which are used in the TMI-1 vessel welds.

The following is a tabulation of the weld wires, the number of available irradiated capsules, the number of sources from which these weld capsules were obtained, and the TMI-1 weld designations in which they are used:

<u>Table No. 1</u>

Linde-80 Weld Wire Nos.	No. of Irradiated Capsules	No. of Capsule Sources	TMI-1 Weld Designations
72105	18	7	WF-70
299L44	5	3	SA-1526 & WF-25
72442	1	1	WF-67
8T1554	0	0	SA-1494
8T1762	0	0	WF-8

Based on the charpy data for these weld capsules, reported in reference No. 5.2, the correlations of the irradiation embrittlement trend for these weld wires were evaluated in accordance with position No. 2 of the R.G. as well as other methods.

The authors of the methodology contained in position No. 2 of the R.G. recognized the difficulties in obtaining large amounts of irradiated surveillance capsules and thus require only a minimum of two capsules in order to apply this method. As can be noted from Table No. 1 of available surveillance capsules, their number exceeds the expectations by the authors of the regulatory guide. Also application of the position No. 2 methodology, while yielding bounding values for the trend, did not yield very satisfactory trends and indicated the need to re-examine the regulatory method as well as examining other methods which could meet the objective of establishing a bounding trend in the RT_{NDT} for these weld metals.

2.2 **Position No. 2 Evaluation:**

Position No. 2 of the R.G. provides a method for establishing a bounding trend in the irradiation embrittlement based on the mean trend in the shift of the irradiated capsules 30 Ft-Lb transition temperature. The irradiated RT_{NDT} is then calculated as the sum of the resulting trend in the shift, the mean initial RT_{NDT}, and a margin term to account for the uncertainty in the initial RT_{NDT} and the uncertainty in the 30 Ft-Lb shift trend.

Position No. 2 is not specific in detail as to how these mean values and uncertainty terms are to be determined. It seems that the intended use of this guidance was based on irradiated surveillance capsules from a single source versus numerous irradiated surveillance capsules from multiple sources such as from an owners group integrated surveillance program.

If the irradiated data is from a single weld specimen, then the mean initial RT_{NDT}, its uncertainty and shift trend are easily addressed because it is all identical material. However, use of such limited data does not address the uncertainty associated with the uniformity of the weld composition throughout its entire length and volume.

If the irradiated data is from an integrated surveillance program, then there can be a wide range in initial RT_{NDT} values as well as in the trends associated with each of the respective capsule sources and the determination of the mean and uncertainty values becomes more complicated.

2.2.1 **Implementation of Position No. 2 with Integrated Program Data:**

Implementation of position No. 2 with integrated surveillance program data is quite straight forward, however, it becomes obvious that there would be a marked difference in results than would be obtained from single source irradiated capsules and that results with multiple source capsules do not consistently yield representation of the trend in RT_{NDT}.

2.2.1.1 **Mean Chemistry Factor Calculation:**

The chemistry factor is calculated by dividing the sum of the products of dRT_{NDT} of each irradiated capsule and its calculated fluence factor by the sum of the squares of the fluence factors. Comparison of the result to a regression of the dRT_{NDT} and fluence factor values of the irradiated data indicates that this is a mean chemistry value.

If this procedure were applied to irradiated capsules from a single source, then it would probably provide a good representation of the shift trend. However, when applied to a class of weld wire shift data where more scatter would be expected, the result would be a trend with lower slope than a bounding trend curve. This could lead to an unconservative RT_{NDT} trend in the higher fluence range.

Thus, the difference between a bounding shift trend and a mean shift trend would have to be made up in the margin term. Doing so would result in unwarranted conservatism in the lower fluence range. Position No. 2 may be providing for this in the margin term by stipulating a standard deviation of 14°F for the shift versus the 7.5 and 8.5°F standard deviation values which were obtained from the regression of weld wire No. 72105 and 299L44 data.

2.2.1.2 **Initial RT_{NDT} and its Std. Deviation:**

The initial RT_{NDT} and standard deviation for the initial RT_{NDT} were calculated by taking the respective mean and standard deviation values of each weld wire unirradiated capsules for which irradiated data was available.

If this were applied to a single source capsule, then the standard deviation would be a small value and the mean value would be representative of the weld metal initial RT_{NDT}. Application of this method to a class of weld wire unirradiated capsules which could have a wide range of initial values, would result in a relatively large standard deviation and the resulting mean value would not be representative of a value to which a shift trend could be applied and yet expect to provide a good representation of the RT_{NDT} trend. Alternatively, data for a given weld wire could have initial RT_{NDT} values which are within a very narrow range, resulting in a small standard deviation value.

2.2.1.3 **Margin Term:**

The margin term is defined by two (2) times the square root of the sum of the squares of the standard deviations associated with the initial RT_{NDT} and the 14°F for the shift.

If the standard deviation of the initial RT_{NDT} is small, then the results of position No. 2 could yield an unconservative trend in the RT_{NDT}. Conversely, if the standard deviation is large, then it would yield excess conservatism in the lower fluence range, as is demonstrated by results of evaluating weld wire No. 72105.

2.2.1.4 **Summary of Position No. 2 Evaluation:**

In summary, position No. 2 does not consistantly provide a representative, or necessarily a bounding, RT_{NDT} trend.

2.3 **Position No. 1 Evaluation:**

Position No. 1 provides a method of projecting bounding RT_{NDT} trends if irradiated surveillance capsule data is not available. These projections are based on the copper and nickel chemistry content in the metals.

The shift (dRT_{NDT}) trend is determined by multiplying the fluence factor by a chemistry factor which is obtained from tables, contained in the R.G., based on the chemistry content of the metal.

The initial RT_{NDT} and its standard deviation are determined in a fashion similar to that which has been described in the discussion of the position No. 2 evaluation, except that all available unirradiated data is included in the calculation. This results in similar large standard deviation values and initial mean RT_{NDT} values which are continually challenged.

2.3.1 **Position No. 1 Chemistry Factor & Shift Trend:**

In applying position No. 1, the chemistry factor is determined from the R.G. tables on the basis of the mean plus one standard deviation of the copper and nickel chemistry content in the integrated surveillance program unirradiated capsules.

The shift trend is then calculated by multiplying the resultant chemistry factor by the fluence factor. Applying this method to the weld wires being evaluated (72105 & 299L44) and plotting the results against the irradiated shift data indicates that the resulting trend nearly bounds all of the data. Thus, it would seem that the chemistry factors obtained from the R.G. tables are bounding values, versus the mean value which are obtained from implementation of position No. 2.

The discussion section in the R.G. indicates that the shift correlation (Eq. No. 2 in R.G.) is a blend of the correlation functions presented in publication by the major contributors to guide. Thus, an evaluation regression of the irradiated shift data to the general form of the correlation was implemented. The resulting mean chemistry factors plus their standard deviation for the weld wires were nearly the same as those which were obtained from the R.G. chemistry factor table, although the exponential constants in the fluence factor were slightly different. This provides another indication that the chemistry factors in the R.G. tables are bounding values.

2.3.2 Initial RT_{NDT} & its Std. Deviation:

The initial RT_{NDT} value and its standard deviation, if calculated on the basis of multiple unirradiated capsules would be expected to result in a mean value and a large standard deviation value as has been discussed in the evaluation of position No. 2.

2.3.3 Margin Term:

The margin term is defined by two (2) times the square root of the sum of the squares of the standard deviations associated with the initial RT_{NDT} and the 28°F for the shift.

Here again, if the data contains a wide range of initial RT_{NDT} values, then a large margin term would be generated. This is compounded by the standard deviation value ascribed for the shift which already seems to be included in the chemistry factor. Thus, there is a double accounting of the uncertainty associated with the shift term.

2.3.4 Position No. 1 Shift Trend vs. Irradiated RT_{NDT} Data:

A check of the calculated position No. 1 shift trend against the irradiated RT_{NDT} data indicates that, for the weld wires being evaluated, the shift trend nearly bounds the irradiated RT_{NDT} data. The significance of this is that for a significant population of capsules for a weld wire in which the data contains a wide variation in initial RT_{NDT} values the irradiated RT_{NDT} data falls within a bounding trend of RT_{NDT}. Examination of the data indicates that capsules with higher initial values have lower shift trends than capsules of the same weld wire with lower initial values. Thus, in determining the bounding RT_{NDT} trend for a weld wire, the significance of the initial value becomes less important and consideration of an alternate method to generate bounding trends of the RT_{NDT} seems to warrant some merit.

2.3.5 **Summary of Position No. 1 Evaluation:**

The position No. 1 procedure of establishing a bounding projection of the RT_{NDT}, if irradiated surveillance data is unavailable, contains a double accounting of the shift uncertainty which should be eliminated from the margin term rather than from the chemistry factor.

Since the shift trend calculated with position No. 1 nearly bounds the RT_{NDT} data for a wide range of initial values, there seems to be a disconnect in the representation of a bounding RT_{NDT} trend by the sum of an initial value and the shift trend.

2.4 Evaluation of Other Methods for Establishing Bounding RT_{NDT} Trends:

The objective being to establish bounding, yet not overly conservative, trends in the RT_{NDT} so that conservative operating P/T limits for the prevention of brittle fracture of the reactor vessel can be generated.

An evaluation of the RT_{NDT} correlation (reference No. 5.4) which examines both position No. 1 and 2 of the regulation as well as other methods concludes that a simpler approach to establishing a bounding trend in RT_{NDT} is justified and would yield a more satisfactory bounding trend.

The discussions in the previous sections addressed the findings regarding both position No. 1 & 2 of the regulatory guide.

Reference No. 5.4 examined various alternative methods which might meet the criteria of generating consistent representative bounding trends of irradiated RT_{NDT}. It the intention of this report to present the method which was found to best meet this criteria and to only briefly discuss some of the methods which were evaluated.

Weld wire No. 72105 has the greatest number of irradiated surveillance capsules from several different sources. Thus, weld wire No. 72105 has been considered to be the primary weld metal by which an assessment of a method which can consistantly yield bounding trends of irradiation embrittlement can be made. The secondary weld wire which could provide such a function is weld wire No. 299L44.

App. A, Figures No. 1 & 2 show the results, for weld wires No. 72105 and 299L44, of some of the methods which were evaluated, including R.G. positions No. 1 & 2. The following is a brief description of the alternate methods:

Position No. 1 Alternate:

This method calculates the shift (dRT_{NDT}) trend in accordance with position No. 1 of the R.G. Then, utilizing the irradiated capsule RT_{NDT} data for the weld wire, the dRT_{NDT} trend is shifted vertically until it bounds all of the RT_{NDT} data points. The amount of the shift is then taken to represent the sum of the initial RT_{NDT} plus the margin term.

If surveillance data is unavailable, then a value for the sum of the initial RT_{NDT} plus margin term of 40°F is justified for the Linde-80 weld metals. This value is justified on the basis that if the double accounting of the standard deviation in the position No. 1 margin term were removed, then the sum of initial value plus margin would be calculated as less than 40°F. A check of this value against the single irradiated data point for weld wire No. 72442 indicates more than adequate margin is afforded by this value, while the calculated value for the irradiated surveillance data for weld wires No. 72105 and 299L44 are 13°F and 10°F, respectively.

Regression:

This method utilizes the R.G. fluence factor and performs a regression of the surveillance capsules RT_{NDT} data to determine a chemistry factor, an initial RT_{NDT} value, and a standard error of the Y estimate which is used as one-half of the margin term.

Alternate Calculation:

This method assumes an initial RT_{NDT} value of zero, and utilizing the R.G. fluence factor calculates a chemistry factor for each irradiated surveillance capsule RT_{NDT}. The maximum calculated chemistry factor is then taken to represent the bounding chemistry factor for the weld wire.

The Position No. 1 Alternate method was evaluated to provide the best method which yields consistent representative bounding RT_{NDT} trends of the Linde-80 weld wires and provides a means of addressing the RT_{NDT} bounding trends even if surveillance data is not available.

App. A, Figures No. 3 & 4 show the resulting RT_{NDT} bounding trends, for weld wires No. 72105 & 299L44, based on position No. 2 method and the Position No. 1 Alternate method.

The following are resulting Position No. 1 Alternate method factors which are utilized to evaluate the TMI-1 reactor vessel welds.

Table No. 2

Weld Metal	SA-1526 & WF-25	WF-70	WF-67	WF-8	SA-1494
Weld Wire No.	299L44	72105	72442	8T1762	8T1554
Chemistry Factor	223.6	210.75	173	153	159
Initial RT_{NDT}	-	-	-	-	-
Margin	10	13	40	40	40
Chemistry					
% Cu	0.35	0.35	0.24	0.20	0.18
% Ni	0.68	0.59	0.60	0.55	0.63

Note that the plate materials of the TMI-1 reactor vessel will be evaluated per R.G. 1.99 Rev. 2, position No. 1.

2.5 TMI-1 Reactor Vessel Fluence Evaluation:

The TMI-1 reactor vessel fluence projections are tracked by a B&WOG activity. These projections are made on the basis of the average fluence which has been calculated in each of the previous two fuel cycles of operation. Since continuous efforts are made to reduce the applied fluence in future fuel cycles, the method of projecting the accumulated fluence at a future point in time is conservative.

Reference No. 5.5 calculates the peak fluence projections at each of the weld and plate locations. This calculation utilizes the methods and results of the B&WOG fluence tracking system to determine the cumulative fluence at the end of each fuel operating cycle, assuming that TMI-1 will continue to operate on a two year refueling cycle and that the availability will be equal to 90% or less. Note that the plant availability factor is used only to estimate the effective full power years (EFPY) as a function of time.

App. A, Figure No. 8 shows the TMI-1 expected end of fuel cycles, the cumulative EFPY, and the calendar year at which they occur, assuming 90% availability factor.

2.6 Evaluation of TMI-1 Reactor Vessel Materials:

The embrittlement (RT_{NDT}) trend of the TMI-1 reactor vessel weld and plate metals can now be calculated as a function of the cumulative fluence.

The embrittlement trend of the plate materials is calculated in accordance with position No. 1 of the regulatory guide, and the embrittlement trend of the weld metals are calculated on the basis of the factors in Table No. 2, above.

Reference No. 5.5 performs this evaluation and yields the trend curves shown in App. A, Figures No. 5, 6, & 7 for vessel welds at the 1/4T, 3/4T and inside surface locations.

The calculation also determines the EFPY and estimated point in time at which the limiting location is projected to attain the RT_{NDT} values which were utilized to generate the 10 EFPY operating P/T limits. The RT_{NDT} values which were utilized to generate the 10 EFPY operating P/T limits had been calculated with the overly conservative position No. 1 procedure. The resulting summary of the embrittlement status of all of the TMI-1 reactor vessel beltline weld and plate materials at 32.3 EFPY is shown in App. A, Table No. 1.

3.0 **Results:**

1 - The TMI-1 operating P/T limits were developed on the basis of an overly conservative projection method (R.G. position No. 1) of the RT_{NDT} at 10 EFPY.

2 - Evaluation of R.G. position No. 1 procedure indicates the reason for the over conservatism to be the double accounting for the uncertainty associated with the irradiation induced shift in RT_{NDT}.

3 - Evaluation of R.G. position No. 2 procedure indicates its potential pitfalls, including the reasons as to it not producing consistent bounding RT_{NDT} trends.

4 - Evaluation of alternative methods for establishing consistent bounding RT_{NDT} trends has determined that a method which is a modification of R.G. position No. 1 procedure (labeled Position No. 1 Alternate) yields a better trend and meets the acceptance criteria for establishing bounding trends of irradiated surveillance data. This method can also be employed for Linde-80 weld wires for which irradiated surveillance data is not available.

5 - Application of R.G. position No.1 method for the plate materials and the Position No. 1 Alternate method for the weld metals to project the RT_{NDT} values for the TMI-1 reactor vessel yields significantly lower values than had been previously projected per the R.G. position No. 1 procedure.

6 - Calculation of the EFPY at which the RT_{NDT} of the controlling beltline material in the TMI-1 reactor vessel is now projected to reach the RT_{NDT} value which was utilized to establish the present operating P/T limits is 32.3 EFPY, with the controlling material remaining as the SA-1526 longitudinal vessel weld.

7 - The resultant RT_{NDT} at the inside surface, or RT_{PTS}, values at the limiting longitudinal weld (SA-1526) and the limiting circumferential weld (WF-25) at 32.3 EFPY are projected to be equal to 217°F and 225°F, respectively, and are thus significantly below the 10 CFR 50.61 screening criteria.

8 - Justification for the acceptability of TMI-1 to operate with C_v-USE values below 50 Ft-Lbs is provided by the B&WOG determination that the Owners Group lead plant analysis bounds the TMI-1 vessel for a 32 EFPY period and that the 10 year ISI inspection of the beltline welds found no unacceptable flaws. A TMI-1 plant specific or an Owners Group bounding analysis will be submitted to the NRC in 1993.

4.0 Conclusions:

The conclusion of the evaluations which have been performed to determine the status of the TMI-1 reactor vessel embrittlement is that the Tech. Spec. period of applicability of the present operating P/T limits for plant heatup and cooldown can be extended from the present 10 EFPY until 32 EFPY are achieved while providing adequate protection from brittle fracture of the vessel.

5.0 References:

5.1 R.G. 1.99 Rev. 2

USNRC Regulatory Guide, "Radiation Embrittlement of Reactor Vessel Materials", dated May 1988.

5.2 BAW-1803 Rev. 1

B&W Owners Group Materials Committee report, "Correlations for Predicting the Effects of Neutron Radiation on Linde-80 Submerged-Arc Welds", dated May 1991.

5.3 C-1101-221-5300-009 Rev. 0

GPUN calculation, "Determination of RT_{NDT} Values for Circumferential versus Longitudinal Oriented R.V. Postulated Flaw to Yield the same P/T Limits", dated 1/11/93.

5.4 C-1101-221-5300-010 Rev. 0

GPUN calculation, "Determination of RT_{NDT} Correlation per R.G. 1.99 Rev. 2, for Linde-80 Welds" dated 1/18/93.

5.5 C-1101-221-5300-011 Rev. 0

GPUN calculation, "TMI-1 Reactor Vessel Welds Fluence and RT_{NDT} per R.G. 1.99 R-2, Position No. 2, versus Time", dated 1/18/93.

Appendix A

Appendix A

Table No. 1

Summary of TMI-1 Reactor Vessel Plates & Welds RTndt Evaluation

Availability Factor = 0.9 **; EFPY =** 32.3 **; Year =** 2018.6 **; Cycle =** 21.4

Location I.D.	R.V. Beltline Region Location	Chemistry		FLUENCE			RTndt			R.G. 1.99 R-2
		COPPER %	NICKEL %	@ I.D. Surf.	@ 1/4T	@ 3/4T	@ I.D. Surf.	@ 1/4T	@ 3/4T	RTndt Basis
PLATE ID										
ARY 59	Lower Nozz. Belt (NB)	0.08	0.72	7.96E+18	4.80E+18	1.74E+18	120	113	99	Pos. No. 1
C2789-1	Upper Shell (US)	0.09	0.57	8.68E+18	5.23E+18	1.90E+18	119	111	95	Pos. No. 1
C2789-2	Upper Shell (US)	0.09	0.57	8.68E+18	5.23E+18	1.90E+18	119	111	95	Pos. No. 1
C3307-1	Lower Shell (LS)	0.12	0.55	9.04E+18	5.45E+18	1.98E+18	143	131	109	Pos. No. 1
C3251-1	Lower Shell (LS)	0.11	0.50	9.04E+18	5.45E+18	1.98E+18	134	124	104	Pos. No. 1
WELD ID										
WF-70	NB to US Circ. Weld (100%)	0.35	0.59	7.96E+18	4.80E+18	1.74E+18	210	181	126	Pos. No. 1 Alt.
WF-25	US to LS Circ. Weld (100%)	0.35	0.68	8.68E+18	5.23E+18	1.90E+18	225	193	135	Pos. No. 1 Alt.
WF-67	LS to Dutch Circ. Weld (ID 50%)	0.24	0.60	5.06E+16	3.05E+16	1.11E+16	52	48	43	Pos. No. 1 Alt.
WF-70	LS to Dutch Circ. Weld (OD 50%)	0.35	0.59	5.06E+16	3.05E+16	1.11E+16	N/A	N/A	17	Pos. No. 1 Alt.
WF-8	US Long. Weld (100%)	0.20	0.55	9.04E+18	5.45E+18	1.98E+18	189	167	127	Pos. No. 1 Alt.
SA-1526	LS Long. Weld (ID 37%)	0.35	0.68	7.73E+18	4.66E+18	1.69E+18	217	186	129	Pos. No. 1 Alt.
SA-1494	LS Long. Weld (OD 63%)	0.18	0.68	7.73E+18	4.66E+18	1.69E+18	N/A	N/A	124	Pos. No. 1 Alt.

NOTES :

(1) FLUENCE: NEUTRON FLUENCE 10**19 n/cm**2 FOR E>= 1MeV based on peak flux values and location adjustment factors from BAW-2108 Rev. 1, dated May, 1992.

(2) Weld SA-1526 is still considered to be the controlling location in the TMI-1 reactor vessel.

(3) RTndt values for welds WF-8, WF-67 & SA-1494 are calculated on the basis of Pos. No. 1 Alt. method since R.G. 1.99 Rev. No. 2, Position No. 1 method is overly conservative (Ref. No. 6).

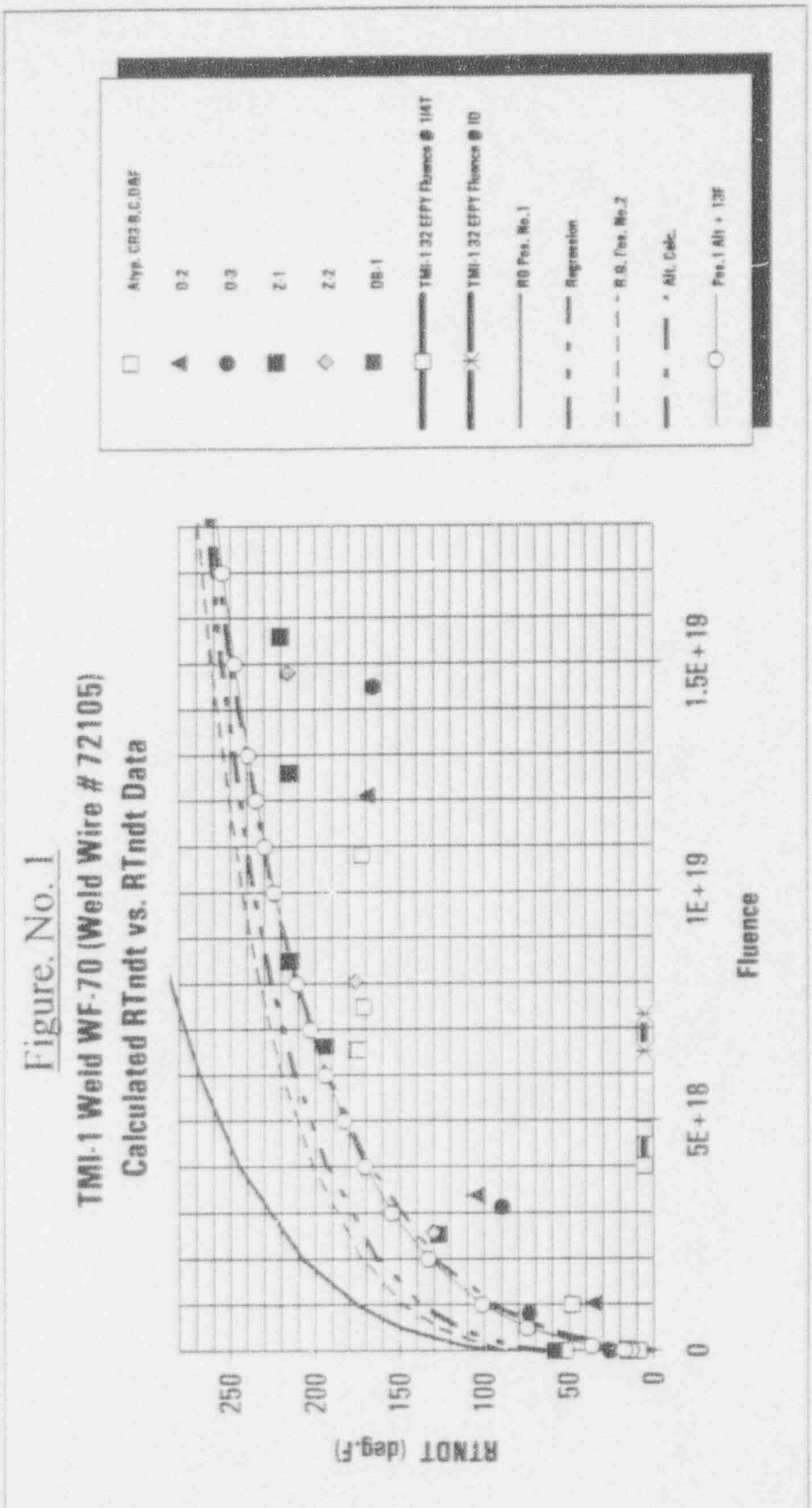
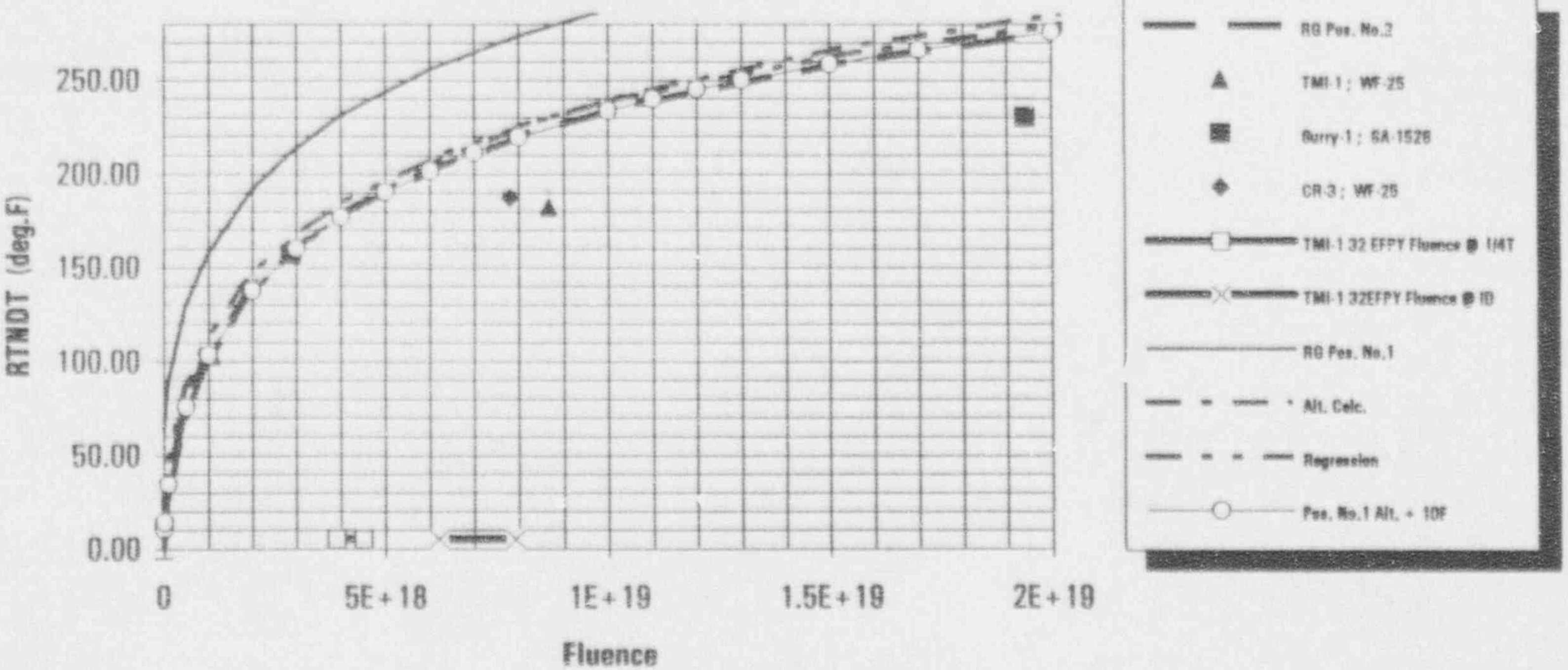


Figure. No. 1
TMI-1 Weld WF-70 (Weld Wire # 72105)
Calculated RTndt vs. RTndt Data
RTNDT (deg.F)
0
50
100
150
200
250
0
5E+18
1E+19
1.5E+19
Fluence
Alyp. CR3 8.C.DAF
D2
D3
Z1
Z2
DB-1
TMI-1 32 EFPY Fluence @ 1/4T
TMI-1 32 EFPY Fluence @ ID
RG Pos. No.1
Regression
R.G. Pos. No.2
Alt. Calc.
Pos.1 Alt + 13F

Figure No. 2

TMI-1 Welds SA-1526 & WF-25 (Weld Wire # 299L44)

Calculated RTndt vs. RTndt Data



TR095FIG.XLS

Figure No. 3

WF-70 & WF-209 Surveillance Data
versus
Weld Wire # 72105 Bounding Trends

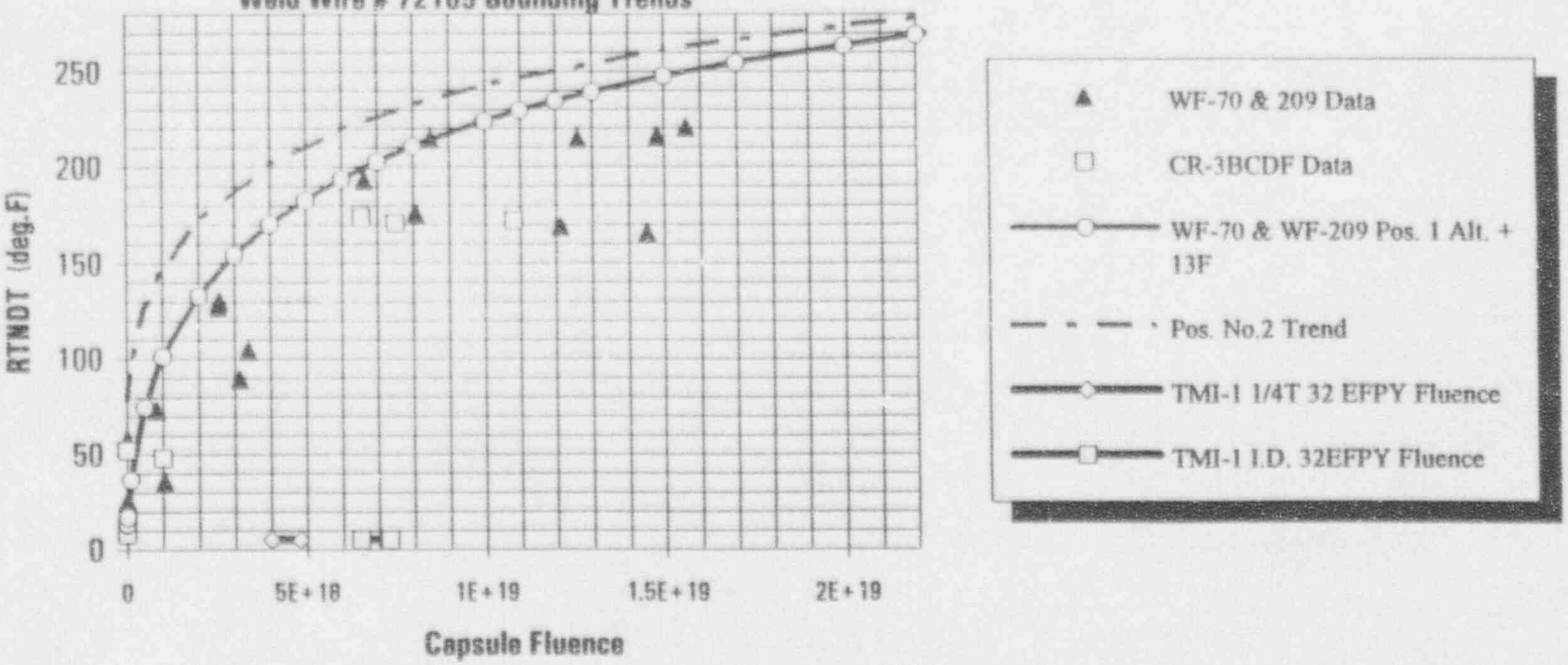
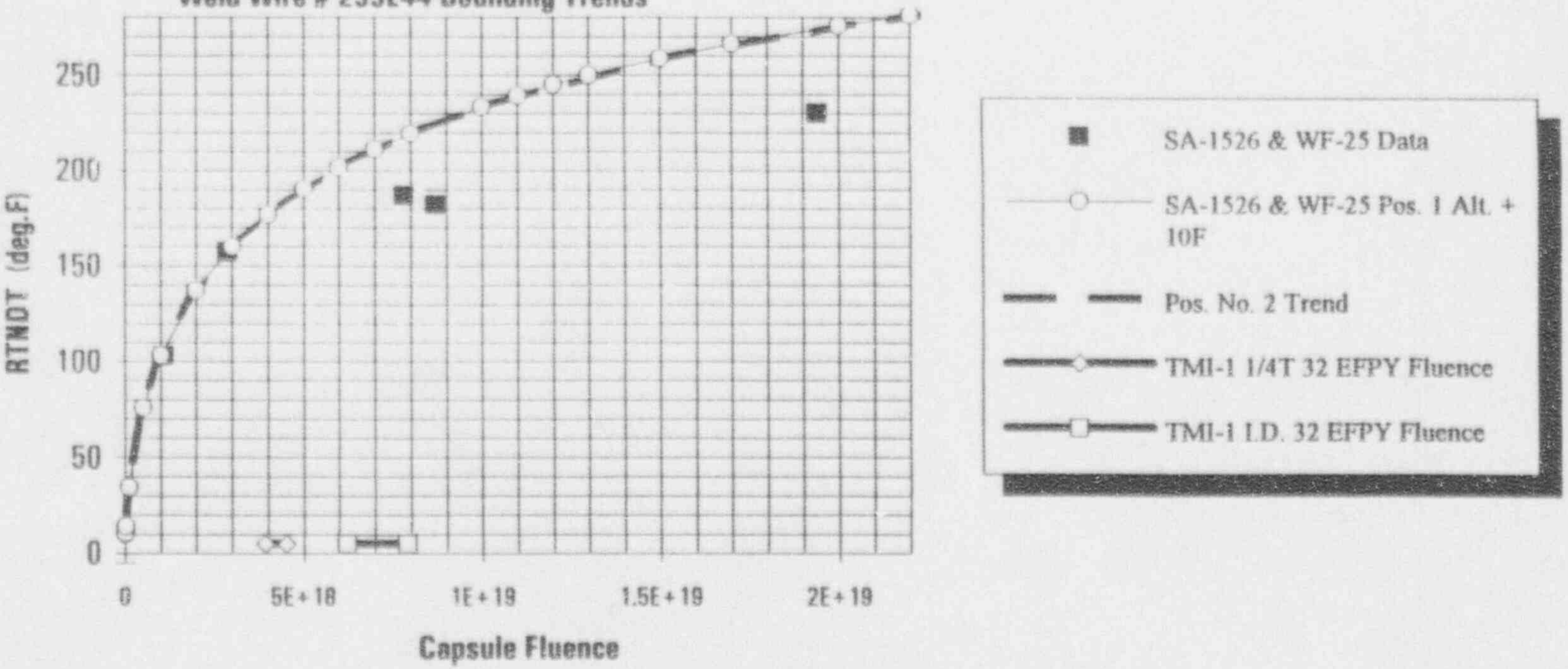


Figure No. 4

SA-1526 &WF-25 Surveillance Data
versus
Weld Wire # 299L44 Bounding Trends



TR095FIG.XLS

Figure No. 5a

TMI-1 1/4T RTndt

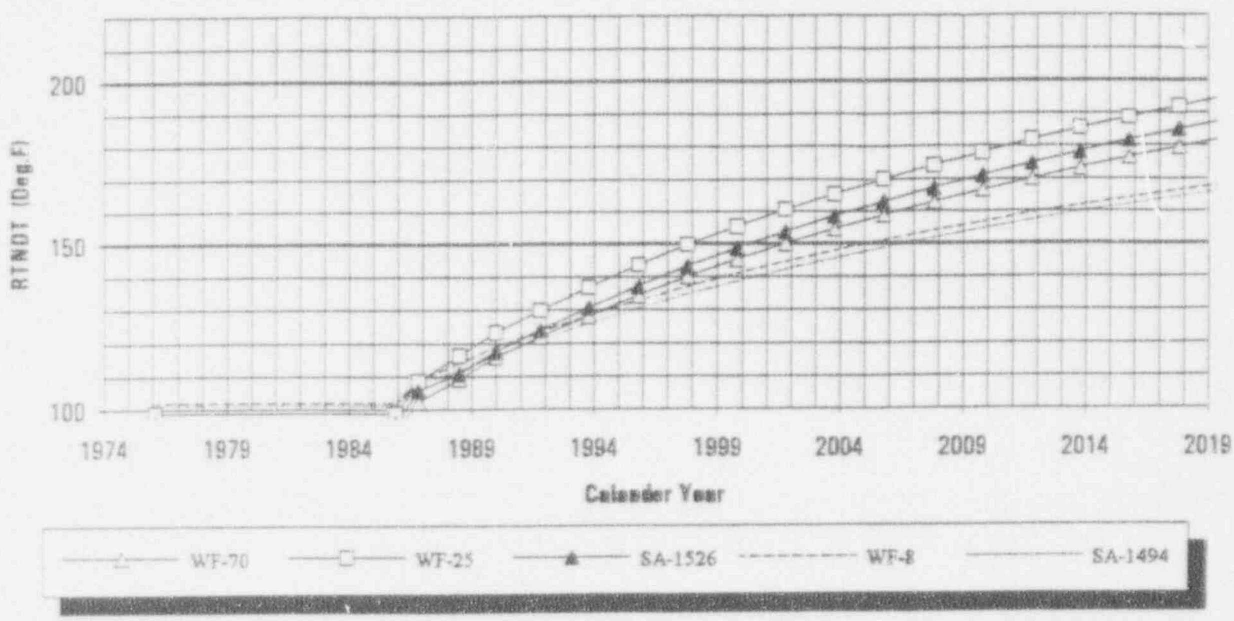


Figure No. 5b

TMI-1 1/4T RTndt

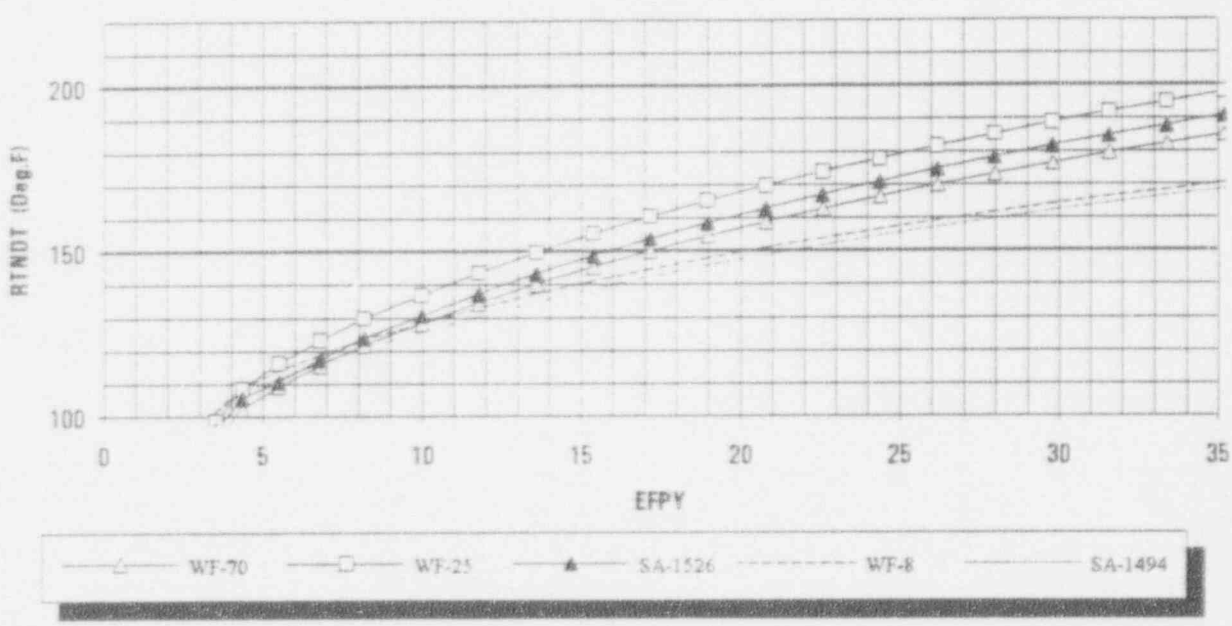


Figure No. 6a

TMI-1 I.D. Surface RTndt

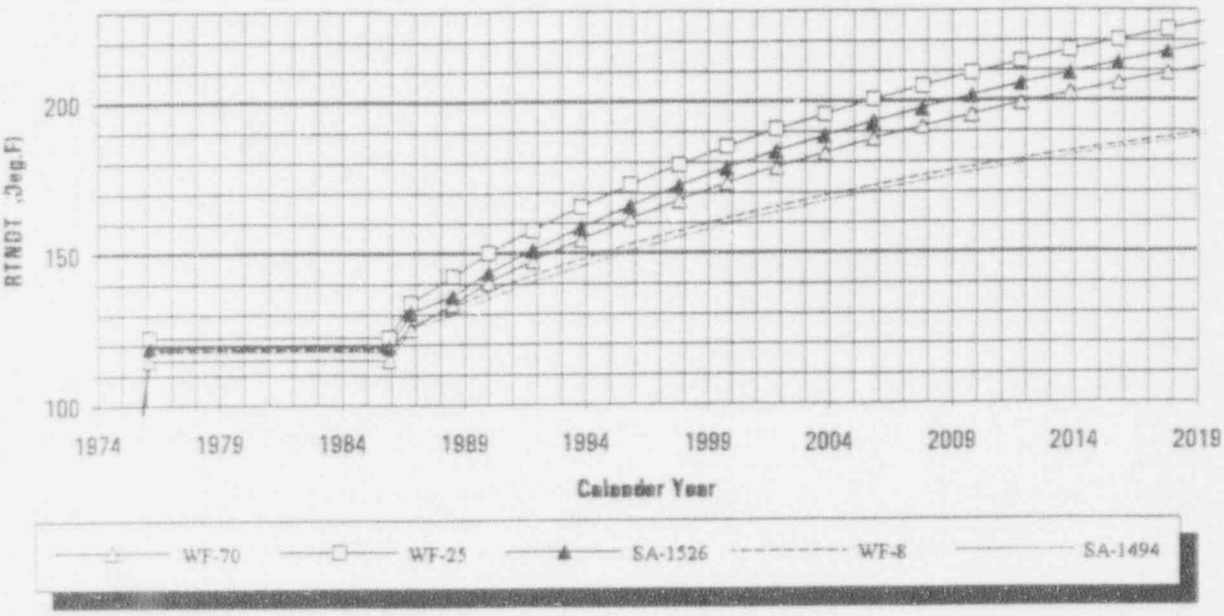
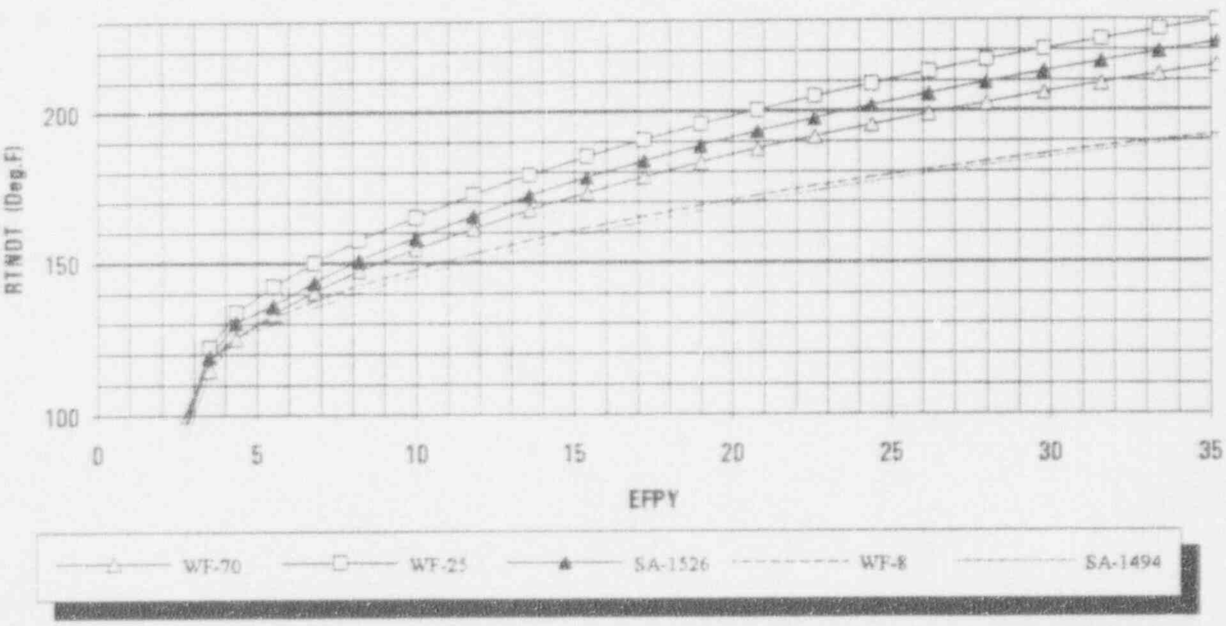


Figure No. 6b

TMI-1 I.D. Surface RTndt



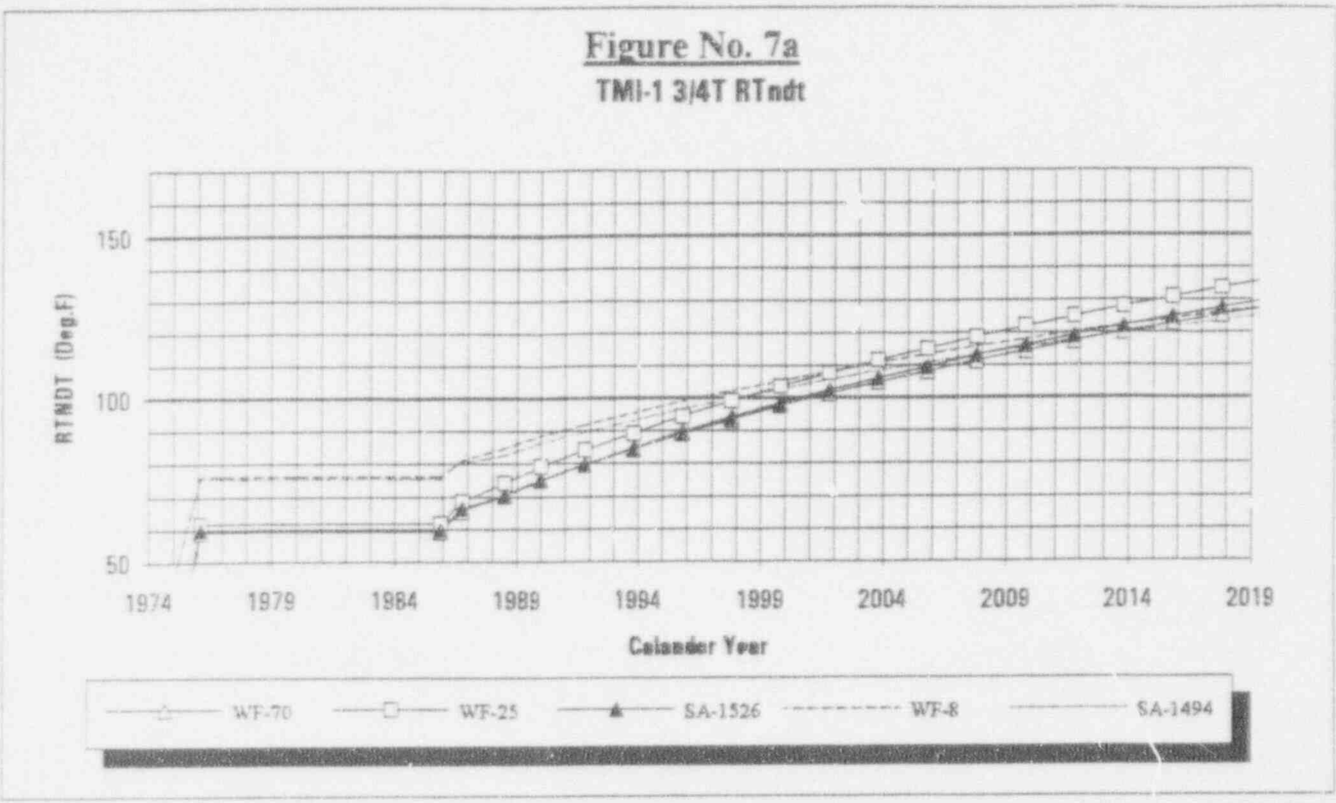


Figure No. 7a
TMI-1 3/4T RTndt
150
100
50
RTNDT (Deg.F)
1974
1979
1984
1989
1994
1999
2004
2009
2014
2019
Calander Year
WF-70
WF-25
SA-1526
WF-8
SA-1494

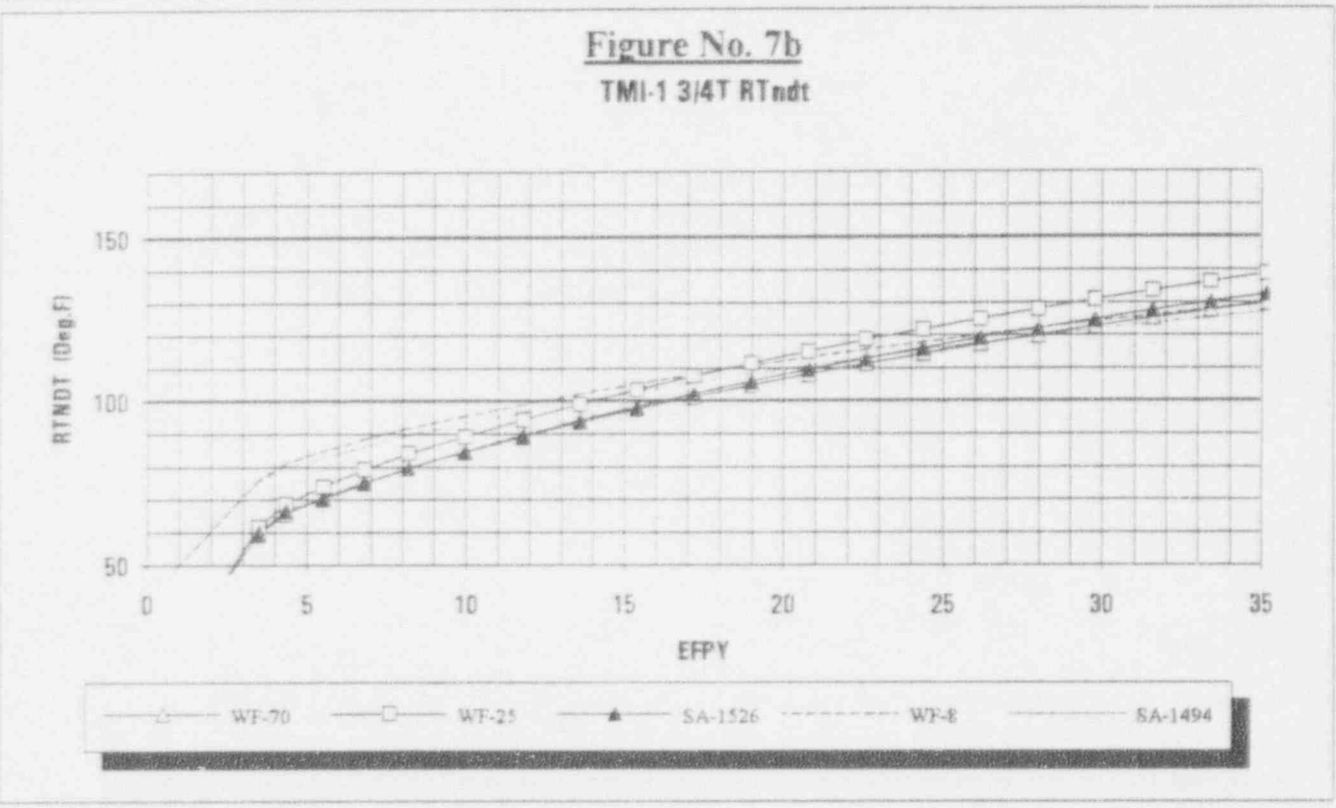


Figure No. 7b
TMI-1 3/4T RTndt
150
100
50
RTNDT (Deg.F)
0
5
10
15
20
25
30
35
EFPY
WF-70
WF-25
SA-1526
WF-8
SA-1494

Figure No. 8

TMI-1 Fuel Cycle & Cummulative EFPY versus Calander @ 90% Availability