REGULATORY ANALYSIS

REGULATORY GUIDE 1.99, REVISION 2

RADIATION DAMAGE TO REACTOR VESSEL MATERIALS

1. STATEMENT OF THE PROBLEM

One obvious constraint on the operation of a reactor is prevention of fracture of the vessel. This is accomplished, in part, by warming it before pressurization, following the pressure-temperature (P-T) limits given in the Technical Specifications (Tech Specs). Neutron radiation damage to the reactor vessel is compensated for by shifting the P-T limits up the temperature scale every few years by an amount corresponding to the shift in the Charpy test transition temperature produced by the accumulated neutron fluence. The NRC regulates this process on the basis of Appendices G and H, 10 CFR Part 50. Paragraph V.A of Appendix G requires: "The effects of neutron radiation...are to be predicted from the results of pertinent radiation effects studies...."

Since Revision 1 of Regulatory Guide 1.99 was published eight years ago, there has been a significant accumulation of power reactor surveillance data, which constitutes a much more pertinent basis for the Guide than was available when Revision 1 was written. Revision 2 is based entirely on the surveillance data, and its issuance will provide a basis for licensing decisions that constitutes the most pertinent results available, in conformance with the regulation.

It may be asked why the Guide is needed if plants now have surveillance data of their own. Of course, for the newer plants such data are not yet available. For many older plants, unfortunately, the materials in the surveillance capsules are not the controlling materials for that reactor according to our present day understanding. Thus, instead of using the plants' own surveillance results directly, the staff must rely on calculated values based on the chemical composition of the vessel materials and the neutron fluence.

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Regulatory Guide 1.99 Revision 2 upgrades and expands the calculative procedures that are acceptable to the NRC, and it describes acceptable procedures for using plant-specific surveillance data when they become available.

The Guide is used in any regulatory action that requires knowledge of the fracture toughness of reactor vessel beltline materials. Three examples of such actions are: (1) setting pressure - temperature (P-T) limits for heatup and cooldown, (2) evaluating transients that threaten the integrity of the reactor vessel, such as low temperature overpressurization and pressurized thermal shock events, (3) evaluating flaws found during inspection. In any of these analyses, a key input to the calculation is the fracture toughness of the material as a function of temperature. The ASME Code gives reference values of toughness as a function of temperature relative to RT_{NDT}, the "reference temperature nil-ductility transition" of the material. The Code also describes how to measure the initial RT_{NDT} for the unirradiated material. This Guide gives calculative procedures for ΔRT_{NDT}, the adjustment of RT_{NDT} caused by neutron radiation. The Guide also describes how to combine the initial and the "delta" with a suitable margin to obtain a value of RT_{NDT} that covers the uncertainties in both.

From analysis of the new data base, and from experience in applying the Guide, the need for certain changes became clear.

- Nickel has been found to increase the Charpy shift in the presence of copper, and should be a factor in the calculations. Thus, some reactor vessels with high nickel welds, which were made when nickel was added in the welding process, have more susceptibility to radiation than previously thought. Conversely, some early reactor vessels that were made with no deliberate alloying additions of nickel have lower sensitivity to radiation. Implementation of Revision 2 will remedy these situations.

- The effects of copper and nickel content on the sensitivity of welds to radiation damage are different than they are for base metal--so different as to require separate treatment of welds and base metal in this Guide.

- The fluence function needs revision.

- The calculative procedure needs to be amended to prescribe mean values instead of upper bound values and to state the margin separately.

- Procedures for calculating the attenuation of radiation damage through the vessel wall need to be stated specifically.

- Improved knowledge of scatter in the surveillance data base made it necessary to rewrite the criteria for use of plant-specific surveillance data in setting P-T limits for that reactor.

2. OBJECTIVE

2.a General Objective of Regulatory Guide 1.99

The objective of the guide is best described by reference to the schematic pressure-temperature (P-T) diagram, Figure 1. The following discussion is mainly applicable to PWRs. (See paragraph 4.1.a.6) The upper-left boundary of the operating zone, the P-T limit, appears in the Technical Specifications for all plants together with certain limits on heatup/cooldown rates. The P-T limits are based on Appendix G, 10 CFR 50, which incorporates Appendix G and parts of Section III of the ASME Boiler and Pressure Vessel Code. And, the P-T limits are affected by Regulatory Guide 1.99 as described in the previous Section.

In the upper-left corner of Figure 1 is a region labelled "hazardous to vessel integrity" which is bounded by a set of curves (instead of one curve) to indicate that higher cooldown rates increase the hazards. This boundary moves upscale in temperature as radiation damage accumulates during the operating life of the vessel. The objective of the margins added in calculating P-T limits is to place the operating zone for heatup/cooldown far enough from the hazardous region to provide the operator time to diagnose and correct system transients such as low temperature overpressurizations (LTOPS) and rapid cooldown events that could threaten vessel integrity.

2.a.1 Sources of Margin in P-T Limit Calculations

A discussion of the sources of margin that are present in the calculative procedure for P-T limits given in the ASME Code and NRC Regulations is in order.

First, the postulated flaw is a semiellipse 0.25T deep by 1.5T long (2.2 in. x 13 in., typically, for a PWR). From the flaw size distribution used in the VISA code, the probability of such a flaw in the critical beltline weld of a reactor vessel is about one in 60,000. The probability may be debatable, but clearly there is margin in the 0.25T flaw assumption. Nevertheless, the use of a 0.25T flaw is an accepted feature of the Code procedure for calculation of P-T limits, which we endorse. This is partly because the efficacy of the flaw detection and sizing in non-destructive examination is still debatable, and partly because some flaws are the result of metallurgical conditions that also degrade the toughness of the adjacent material.

Second, there is a safety factor of two on the stress intensity factor due to primary membrane stress (in the beltline, pressure stress) and a factor of one on that due to thermal stress. These factors were chosen by the Code writing bodies with the help of the basic document, WRC Bulletin 175,* but the rationale for the factor of 2 on pressure is not explicitly stated therein.

A third source of margin is the requirement that the toughness-temperature function used in these calculations should be the "K_{Ia} curve" for crack arrest, called the "K_{IR} curve" in Appendix G, rather than the "K_{Ic} curve" for static crack initiation. (See Figure 4 of the Regulatory Analysis). The K_{IR} curve is the lower bound of dynamic and crack arrest toughness values for specimens some of which were full thickness. Its adoption for Appendix G of the ASME Code derived from a philosophy that was subscribed to by many, especially the researchers from the Naval Research Laboratory, that many service failures were the result of dynamic loading. In a reactor vessel beltline, the pressure and thermal stresses are not applied dynamically in the sense intended here, not

*PVRC AdHoc Task Group on Toughness Requirements," PRVC Recommendations on Toughness Requirements for Ferritic Materials," Welding Research Council Bulletin No. 175, August, 1972.

even in a thermal shock situation. However, one can postulate a case for rapid loading by postulating a small defect that is surrounded by a nugget of brittle metal that carries stress up to some critical level, then cracks open suddenly, presenting the sound metal with a running crack. Thus, the requirement to use the crack arrest toughness curve instead of the crack initiation curve is not entirely a matter of adding margin - in some unknown percentage of cases, it is the realistic thing to do. Whether based on this scenario or on simple conservatism, the calculations required by the ASME Code for P-T limits are to be based on the K_{IR} curve. For evaluation of accident conditions, however, Section XI uses the K_{Ic} curve. The temperature difference between the K_{IR} curve and the K_{Ic} curve is about 65°F in the region of interest.

The fourth source of margin in the calculation of P-T limits is the use of lower bound toughness curves. In the VISA code, however, toughness is simulated from the mean K_{Ic} curve with a distribution about the mean of ± 10 per cent (1 sigma). The use of a lower bound curve is consistent with Code philosophy in setting allowables, and was believed justified at the time it was drawn, because the data base was for only one heat of plate material. The temperature margin between the K_{Ic} curve in the Code and the best-estimate curve used in the VISA code is about 40°F in the region of interest. (See Figure 5.)

The fifth source of margin is that required by Revision 2, paragraph C.1.a.(3). Toughness values, K_{IR} and K_{Ic} are given in terms of $(T-RT_{NDT})$. The margin added to RT_{NDT} covers uncertainty in the initial RT_{NDT} for unirradiated material as well as the uncertainty in ΔRT_{NDT}, which is specified in Revision 2 to be 56°F for welds and 34°F for base metal. These values resulted from the regression analyses of the data and represent two-sigma upper bounds. They are considered to cover the uncertainty caused by scatter of the data about the mean and uncertainties in the copper, nickel, and fluence. These variables are entered in the calculative procedure as best-estimate or mean values. The margin also is assumed to cover uncertainty arising from possible differences between the copper and nickel contents of the weld and base metal samples and those of the actual vessel materials at the location of interest in a fracture analysis.

In conclusion, it should be pointed out that the efforts to provide margin in the five areas described above are quite consistent with the requirements of General Design Criterion 31. It states in part "The design shall reflect consideration of ...the uncertainties in determining (1) material properties, (2) the effects of irradiation on material properties, (3) residual, steady state and transient stresses, and (4) size of flaws."

Constraints on the amount of margin that can prudently be provided derive from the need for an operating zone of reasonable width for efficiency in heatup/cooldown operations and the presence of a lower limit on pressure at a given temperature based on avoidance of pump cavitation or thermal hydraulic problems caused by an approach to saturation conditions.

2.b Summary

An attempt has been made to describe the objectives of Regulatory Guide 1.99 by placing it in context with the other documents that provide the basis for procedures to assure prevention of fracture of the reactor vessel and by describing the sources of margin provided in those procedures. The scope of the Guide is restricted to one part of the procedures: to provide an acceptable basis to account for the effects of neutron radiation on the fracture toughness of reactor vessel materials. This is needed in the calculation of P-T limits, in analysis of transients that threaten vessel integrity and in the analysis of beltline flaws.

The objective of Revision 2 is to upgrade the calculative procedures in Regulatory Guide 1.99 by basing them on the most pertinent radiation data and the best available understanding of radiation damage in reactor vessel materials in accordance with 10 CFR 50, Appendix G. The specific changes made in preparing Revision 2 are itemized in Section 1, above.

3. ALTERNATIVES

The alternatives to issuance of Revision 2 are to leave Revision 1 in place or to eliminate the Guide altogether. The latter can be disposed of quickly: the staff reviews several P-T limits per year, plus an occasional transient and

flaw indication and clearly needs a published basis for its reviews. There is at present nothing equivalent to Regulatory Guide 1.99 in the ASME Code. ASTM Standard Guide E-900-83 contains an equation relating the Charpy shift to copper content and fluence; but, it is out of date, and the Standard does not contain guidance on the use of plant-specific surveillance data. The alternative of continuing to use Revision 1 has a safety impact on many plants and penalizes other plants; a detailed analysis of these consequences is given in the following section.

4. CONSEQUENCES

4.a. Costs and Benefits of Alternatives

4.a.1. Application to P-T Limit Calculations

4.a.1.1 Effects on P-T limits for All Plants. In this Section, it will be shown that implementation of Revision 2 will mean that for about one-half of the operating reactors the P-T limits should be moved upscale to higher temperatures by amounts that depend on fluence level and copper and nickel content of the beltline materials.

Referring again to Figure 1, this means that the region labelled "hazardous to vessel integrity" extends farther upscale in temperature than would be predicted if Revision 1 were continued to be used; hence the P-T limit should be moved also, to maintain the margin.

About one sixth of the plants will be able to operate with their present P-T limits for a longer period than previously determined based on Revision 1. The remaining third will be essentially unaffected.

To determine the consequences of changing from Revision 1 to Revision 2 in our review of P-T limits, the first step was to calculate what differences would result if all plants should review their P-T limits this year first according to Revision 1 and then according to Revision 2. The fluence value used for each plant was chosen, assuming that the goal was to have P-T limits that would be good for 4 or 5 years in the case of PWRs and somewhat longer for BWRs.

The importance of fluence level is shown in Figure 2, which illustrates for one material how the "trend curve" from Revision 1 compares to corresponding curves from Revision 2. The trend curve from Revision 1 is an upper bound curve, hence for comparison, the Revision 2 values are mean-plus-margin, calculated as described in the Guide. Note how the two curves from Revision 2 cross that for Revision 1 at fluences of about 3×10^{18} n/cm^2 for base metal and somewhat higher for welds, indicating that plants having 0.35 Cu and 0.6 Ni and low fluences will be ratcheted whereas those having higher fluences will get some benefits. Figure 2 is drawn for 0.35 percent copper and 0.6 percent nickel. For other compositions, the general appearance of the Figure would be similar, with the crossovers occurring at different fluences.

In Figures 3 and 4, the numerical differences between shift values calculated for Revision 1 and those for Revision 2 (mean plus margin) are tabulated for eight copper levels, three nickel levels, and seven fluence levels. In the Figures, the boundaries between conditions for which a plant would be ratcheted (the positive values in the Table), and those under which plants would benefit (the negative values) are indicated.

Having Figures 3 and 4, the effect on each plant of a change from Revision 1 to Revision 2 as a basis for the P-T limits was readily estimated on the basis of the copper and nickel content of its critical material and the fluence value described above. For the eight plants ratcheted 50-100°F, actual shift calculations were made following Revisions 1 and 2.

Our information on the limiting material and its copper and nickel content was quite good for PWR operating reactors, fairly complete for operating BWRs, but for many plants under construction it was limited to knowing whether or not the reactor vessel was bought to a low-copper specification. However, inspection of Figures 3 and 4 shows that the numbers do not vary radically from box to box in most cases, and we believe the results are sufficiently accurate for discussion purposes.

Table 1 presents a summary of the changes in P-T limits that would result from a change from Revision 1 to Revision 2. For example, the Table shows that, of the 81 operating light-water reactors (including three that are licensed

only for low power testing), about 30 would find little difference (±20°F) in the use of Revision 2 or Revision 1. Eight plants (four PWRs and four BWRs) would find that the use of Revision 2 would raise their P-T limits somewhere between 50°F and 100°F. The features that made this happen were: high nickel welds in three cases, and low fluences in five cases. Some 33 plants would be ratcheted 20-50°F. A total of 10 plants would be benefitted a significant amount. Most of these have low-nickel material (A302 B plate and welds with only residual nickel content).

Most owners of plants undergoing licensing would find the use of Revision 2 raises their P-T limits 20-50°F, but the impact of this is small because flux reduction programs, the use of low-copper materials, and better information about initial RT_{NDT} will cause the expected end-of-life reference temperature to be less than 200°F even when calculated using Revision 2.

It is important to note that the fluences used in the calculations on which Table I is based correspond to about one-fourth of plant life on the average. Inspection of Figures 3 and 4 reveals that for fluences characteristic of later life, which range from 1 to 7 x 10^{19} n/cm^2 for PWRs, and for copper levels that produce high-shift values, the ratchet effects of Revision 2 (as calculated for Table I) disappear and become benefits during the latter half of the lifetime.

4.a.1.2 <u>Risk Avoided by Using Revision 2</u>. One source of risk of continued operation with P-T limits based on Revision 1 when RT_{NDT} is really higher (as given by Revision 2) depends upon the increased probability that a given transient will threaten the vessel. To illustrate this situation in Figure 1, consider that the hazardous region is expanded to the right, closer to the P-T limit, because its extent really depends on a value of RT_{NDT} based on Revision 2. Thus the operator will be misled by erroneous P-T limits as to the potential severity of the transient and will have less time to take corrective action to avoid the hazardous region.

To quantify the risk that would be avoided if the P-T limits were moved upscale to conform to Revision 2, several factors must be evaluated:

a. Expected frequency of transients that may violate P-T limits.

b. Expected severity of transients in terms of pressure and temperature as functions of time.

c. Reduction in severity caused by having proper P-T limits and therefore more concern on the part of the operator and more time to take corrective action. This factor must be evaluated as a function of the difference in P-T limits based on Revisions 1 and 2.

A quantitative evaluation of these factors was not undertaken, because it appeared that uncertainties, particularly in item c, would be so large that the result might not be defensible.

Another source of risk is incurred by a heatup-cooldown operation following P-T limits that are lower than they should be. Consider, for example, one of the plants for which the P-T limits based on Revision 1 are 100°F below those based on Revision 2. If a plant in that situation continued to operate with a P-T limit based on Revision 1, and if the operator followed the limits closely in a heatup - cooldown sequence, there would be greater probability of fracture of the vessel. A contract was given to Pacific Northwest Laboratories (PNL) to evaluate the increased risk, calculate the public exposure to radiation as a consequence of vessel failure, and calculate the costs resulting from a change to Revision 2 as the basis for P-T limits. The PNL report is Enclosure 6.

The change in the probability of fracture (Rev. 1 - Rev. 2) was calculated using a Monte Carlo technique and the VISA code, which originated at the NRC and is being further developed at PNL. In this analysis, initial RT_{NDT}, toughness, copper content, fluence, and flaw size were treated probabilistically. Actually, in most runs, the flaw size had to be treated as fixed at a large value (a 2 in. deep continuous flaw, probability of one) to get the Monte Carlo procedure to produce failures frequently enough to keep the required total runs to a reasonable number. Then the probability was reduced by a factor of 3500 to account for the more realistic flaw size distribution normally used, as explained in the PNL report.

The conclusion reached by PNL, based on the probabilistic fracture mechanics analysis, was that the best estimate of the increase in probability of vessel failure resulting from following P-T limits that were 100°F too low was 2.5 E-7 per heatup/cooldown cycle. In the subsequent risk analysis, this result was used for plants ratcheted 50-100°F and half that amount for plants ratcheted 20-50°F. Using the techniques described in Enclosure 6, PNL completed the calculation of increased public risk resulting from these vessel failure probabilities. For the lifetime of the present population of plants, the total man-rem avoided was 1.1 E+4 man-rem.

4.a.1.3 Costs to Industry--PNL Value/Impact Analysis. The cost of adopting Rev. 2 derives mainly from the cost of purchased power during delays in startup caused by the more restrictive operating limits. In the PNL analysis, Enclosure 6, the extra time involved was estimated to be 2 hours for the worst case of a 100°F ratchet, based on the opinions of their contacts among inspectors and utilities. When the P-T limit is moved upscale, the effect is to increase time spent at low pressure during heatup/cooldown, and the time was calculated by dividing 100°F by 50°F/hr, a typical heatup rate limit. The PNL estimate of industry operating cost is based on an average power cost of $300,000 per EFPD for all plants. Thus, for the 8 plants that are expected to be ratcheted 50-100°F an estimated delay of 2 hours per heatup, and 6 heatup/cooldown cycles per year, the cost will be $150,000 per year per plant for the next 25 years. The 77 plants, including those undergoing licensing, that are expected to be ratcheted 20-50°F per year are assumed to incur half that amount. The best estimate present value of these industry operating costs was given by PNL as $101,000,000 and the net cost to the industry was $63,000,000. The bottom line, best estimate, cost per man-rem saved reported by PNL is "in the $3,500-$5,600 range."

4.a.1.4 Costs to Industry - NRC Cost Analysis Group The NRC's Cost Analysis Group (CAG) made a number of substantive comments about the September, 1984 draft of the PNL report and also did a complete recalculation of the industry operating cost. (See Enclosures 7 and 8) In this work, CAG used their own plant specific power costs as well as plant specific values of the extra heatup time required as calculated by MEBR from the actual difference in P-T limits per Revision 2, relative to those per Revision 1. Their industry operating

cost figure was $71,000,000. If this figure is substituted for the PNL figure of $101,000,000 in the PNL cost estimate, the net cost to industry (See Section 4 of Enclosure 6) of $33,000,000 instead of the PNL figure of $63,000,000. (Further reduction of this cost figure may be justified as discussed in paragraph 4.a.1.6.) This use of the CAG cost estimate reduces the bottom line to $1,800-$2,900 per man-rem-saved.

There is also a paper work cost to the industry when a Tech. Spec. change is prepared and submitted to the NRC. PNL's best estimate of this is $2270 per plant--too small to enter into the cost benefit analysis.

4.a.1.5 Costs to Industry--Corrections Based on Comments Received During Concurrence. The PNL estimate of 6 startup/shutdowns per plant year was questioned by the staff. It had been based on reactor scram data available to PNL. However, after a scram, The plant does not necessarily go to cold shutdown. In the plant operating data given in NUREG-0020, shutdowns greater than 72 hours are tabulated for each month. After correcting for the refueling shutdown, which extends over several months, the average over a three-year period, 1982-4 was 4.3 shutdowns greater than 72 hours per reactor year. From an ORNL analysis of plant operation for 1982, there were approximately 2.0 shutdowns per reactor year greater than 120 hours. Based on these data, and assuming that some of the 72-hour shutdowns were not cold shutdowns, it seems reasonable to assume that there are no more than three startup/shutdown operations per reactor year instead of six as assumed by PNL. This correction reduces the bottom line to $900-1400 per man-rem-saved.

Consideration has also been given to the estimate of 2 hours extra heatup time, caused by the P-T limits being moved upscale by 100°F. The PNL estimate was based on simple division, assuming a heatup rate of 50°F per hour. The rationale was that any restriction to the operating zone (see Figure 1) would require more care in heatup/cooldown and therefore take more time. From data located by R. R. Riggs, SPEB, in EPRI NP-1139, Vol. 2 for PWRs, the average startup time from cold shutdown to hot standby conditions is 20 hours. The average shutdown time, hot to cold, is 14 hours. If it takes 34 hours for an

average startup/shutdown operation (from cold shutdown to hot standby and back) it appears that 2 hours is almost "lost in the noise."

There must be a number of operational factors that determine the critical path, and it is doubtful that the restriction in the operating zone is normally a critical path item considering the number of testing and operational procedures involved in a startup from cold shutdown. Moreover, the ratchet effect of Revision 2 is at a maximum early in plant life when the operating zone has its greatest breadth. In effect, adoption of Revision 2 will simply mean that anticipated restrictions in the operating zone will occur sooner than expected. Consequently, among the list of uncertainties to be itemized later, there is the judgment that the 2 hour figure, and the corresponding cost to industry of $25,000 per startup/shutdown, is probably an upper bound, and the lower bound is nearly zero.

Conservatism in the PNL analysis that affects both cost and risk is the assumption that the ratchets shown in Table I are constant for the remainder of plant life. For the majority of those ratcheted 50-100°F, this may be true, but for some plants the ratchet steadily decreases and becomes a benefit as early as mid-life of the plant. However, the risk reductions also diminish. It has been assumed that their ratio, the dollars per man-rem "bottom line" remains constant. Clearly, there is uncertainty in the assumption that the risks and the present value of the costs are the same function of the ratchet, but it has been made for want of better information.

4.a.1.6 <u>Boiling Water Reactors -- Special Considerations</u> Boiling water reactors, four of which would be ratcheted 50-100°F according to Table I, should probably be omitted from the calculation of both cost and risk associated with heatup/cooldown operations, because saturation conditions govern the pressure at any temperature even during transients if the vessel is not water solid. This consideration would reduce the $33,000,000 industry cost estimate to about $21,000,000, or about one-third of the original PNL cost estimate.

It is during hydrotests and leak tests that BWRs may be affected by Regulatory Guide 1.99. The margins required for hydrotest are given by the ASME Code and Appendix G, 10 CFR 50 just as they are for normal operation, except the

factor of safety on pressure is 1.5 for hydrotest instead of 2.0. A number of BWRs are now at the level of radiation damage where the required metal temperature at the hydrotest pressure is nearing 200°F. This causes two problems, according to verbal reports from some BWR owners representatives. Heatup with pump power apparently is slow in BWRs, compared to PWRs. Also, prolonged operation of the pumps at low pressure causes extra wear of the pump seals. In any case, it takes longer to get to the higher temperature.

The other problem arises from a requirement in the Technical Specifications that the containment drywell be closed when water temperature approaches 212°F. Inerting is not required for 24 hours or more, so entry can be made for leak test inspections, but the time required is increased. Yet, the hydrotest temperature for PWRs exceeds 200°F in many cases; hence, the problem of inspecting for leaks must be manageable. These delays occur after refueling, normally about once every 18 months. Data from R. Riggs (EPRI NP 1136, Vol. 1) show the mean time to conduct a hydrotest of a BWR is 28 hours, with a standard deviation of 6 hours. Thus the impact (time/cost) on BWRs likely falls within the standard deviation of the hydrotest time interval.

Risks incurred during hydrotest are probably small. It is debatable whether or not the margin of 1.5 on pressure required by the Code, compared to a margin of 2.0 for normal operation, properly weighs the relative risks. However, any change in these values involves an amendment to Appendix G, 10 CFR 50 and is beyond the scope of Regulatory Guide 1.99. It is concluded that the BWR hydrotest situation represents little change in the direction of cost per man-rem-saved ($900-$1400, as discussed in 4.a.1.5). The effect is undoubtedly plant specific because the conclusion depends on operational details involved in conducting hydrotests and leak tests.

4.a.1.7 Effects on LTOP Limits After a number of low temperature overpressurizations occurred in the 1970's, a requirement was placed on PWRs to provide automatic pressure relief at low temperatures that would prevent violation of the pressure-temperature limits. Some plants accomplish this by enabling a low setpoint setting on the pressure operated relief valves (PORVs) when at low temperatures. Others use the relief valves in the residual heat removal system (RHR) to provide this function.

For PWRs that would have the P-T limits moved up the temperature scale if the limits were based on Revision 2, the allowable pressure at the cold shutdown temperature, say 140°F for example, would be slightly reduced. The amount is small, because the P-T limit curve is flat at those temperatures, especially for vessels with a large radiation shift. Unfortunately, the system constraints are tight. The reactor coolant pumps (RCP) used in Westinghouse plants require a pressure of about 325 psig minimum for proper function of the seals.

Typical settings of the PORV for LTOP protection are 400-500 psig for temperatures up to about 350°F. This restriction on the operating zone probably accounts for most of the impact on startup time.

In his memorandum to B. D. Liaw, February 27, 1985 commenting on Revision 2, B. J. Elliot wrote:

> Thus, to begin heatup with these limitations, the reactor vessel is pressurized to approximately 350 psig using RHR and CVCS pumps prior to initiating flow through the RCPs. The RCPs are the main source of heat prior to core critical operations. At temperatures below 350°F, the reactor coolant pressure (RCP) must be maintained below the LTOP pressure set-point of 400 psig, since actuation of the LTOP valves would depressurize the system and heatup would have to begin again. The LTOP set points for pressure and temperature are derived from the pressure-temperature limits. Hence, a change in the pressure-temperature limit requires an adjustment in the LTOP set-points. The narrowing of the operating band that results from RCP minimum pressurize and the LTOP set-point, as plants age, has been recognized as a problem by the staff and NSSS vendors. NSSS vendors are reevaluating critical component limitations and operating procedures to determine whether the low temperature operating band may be widened. The staff, in a letter from B. W. Sheron to W. Minners dated August 1, 1984, has requested that the LTOP criteria for operating plants be prioritized as a new generic issue.

The last sentence in the quotation refers to another aspect of the LTOP issue. At Maine Yankee, the requirements for LTOP protection have been broadened to mean there should be automatic protection for the P-T limits at high temperatures as well as low. Until recently, this was provided by the

normal high setpoint on the PORVs, because the temperature at which the RHR system was isolated was higher than the P-T limit temperature at 2250 psig. (See AEOD Engineering Evaluation Report No. E426, October 24, 1984, by E. V. Imbro).

Actually, Maine Yankee is not affected by Revision 2, because there are sufficient credible surveillance data. They show relatively large shift, however, and the P-T limits have been moved upscale so far that the operators elected to add a PORV setpoint at an intermediate pressure.

At present, the NRC does not require automatic protection of the P-T limits at the higher temperatures. If that becomes a requirement, Revision 2 may have some impact on this new aspect of LTOP requirements as well.

4.a.1.8 Costs to NRC. The immediate impact of proposed changes on NRC staff review time will be minimal, because we plan to implement Revision 2 for P-T limit calculations at the regularly scheduled times, as described in Section 6. However, the 3-year limit on implementation will crowd the calendar for review of P-T limits somewhat.

4.a.1.9 Summary of Uncertainties and Conclusions re: Application of Revision 2 to P-T Limits The conclusion reached by PNL - that the costs per man-rem were in the range $3500-5600 has been corrected based on more detailed power cost analysis by CAG (paragraph 4.a.1.4) and on data collected by the staff with regard to the number of cold shutdown per reactor year to yield a value of $900-1400 per man-rem. The following uncertainties have been identified in this result the net effect of which is believed to reduce it significantly, but it has not been possible to further quantify the number.

The most important uncertainty is in the risk term. In paragraph 4.a.1.2 and Figure 1, it was shown that the principal safety function of P-T limits is to separate the operating zone far enough from the zone that is hazardous to vessel integrity to give time for corrective action to mitigate a transient. Regulatory Guide 1.99, being part of the bases for calculating P-T limits, affects the margin provided. For reasons given previously, it was not possible

to quantify the risk avoided by a given correction to the P-T limits, but it is believed to be a larger source of risk than the one PNL was asked to evaluate.

The second most important uncertainty is in the cost term. The principal cost to industry is the cost of power not generated because of delays in startup/shutdown operations caused by restrictions in the operating zone if the P-T limits are moved upscale. The PNL estimate of two hours per startup is believed to be high for most plants, as discussed in paragraph 4.a.1.5. The narrowing of the operating zone resulting from adoption of Revision 2 in certain plants is not significant early in life when the operating zone is broad. Moreover, it is no more severe than was expected to occur late in life. Finally, at higher fluences the "ratchet" disappears, because of differences in the fluence functions given in Revisions 1 and 2. All of these uncertainties are in the direction of significantly reducing the PNL cost estimate.

4.a.2 Other Applications of R.G. 1.99

Regulatory Guide 1.99 is used whenever RT_{NDT} must be calculated as part of an analysis of a transient that has actually occurred. The analysis provides the basis for deciding if the possibility that the vessel has been damaged is sufficiently high to warrant an inspection before returning it to service. Such inspections are time consuming and costly in terms of power replacement.

Another application of Regulatory Guide 1.99 is in the analysis of flaws found by inservice inspection of the reactor vessel beltline. A recent example occurred at Indian Point 2. First, the draft Revision 2 was used to calculate RT_{NDT} at the inside surface, based on the fluence and the weld and plate chemistry. Second, because the flaw was near the outside surface, the formula for attenuation of ΔRT_{NDT} through the vessel wall, (a feature of Revision 2), was used to calculate ΔRT_{NDT} at the tip of the flaw. The evaluation is the basis for deciding if the vessel must be repaired before being put back in service.

In evaluations of transients and flaws there may be significant safety questions, the cost impact may be high, and contention over the decisions may surface. Clearly, it is important to have a basis for the calculation of

radiation damage effects that has had public review and resolution of outstanding issues.

4.b. Impact On Other Requirements

4.b.1 Impact on the Pressurized Thermal Shock Rule

In the PTS rule, SECY 85-60, February 20, 1985 there is a formula for calculating RT_{NDT} (called RT_{PTS} to distinguish that method from others), which is based on an early version of the formulas that are the basis for Revision 2. There are several differences. For the calculation of RT_{PTS}: (1) weld and base metal data were analyzed as one data base yielding one correlation function, (2) the fluence function was of simpler form, and (3) there was a second equation which gave bounding values.

It is not intended to change the proposed PTS Rule to incorporate the latest formula for RT_{NDT}. (Note, however, the action recommended below.) The calculation of RT_{NDT} required by the PTS rule is associated with screening criteria (270°F for base metal and axial welds, 300°F for circumferential welds), which were justified by a probabilistic analysis that considered all identifiable uncertainties including those in the calculation of RT_{NDT}. At the time the Rule was drafted, it was recognized that there would be an evolution in the calculative procedures, but there would be too many actions taken by the utilities in the area of flux reduction programs and other measures to permit frequent changes in the position of every plant relative to the screening criteria.

However, when it appears that the screening criteria will be exceeded at a specific plant, the PTS Rule requires an evaluation of all aspects of the PTS analysis as they apply to that plant. That re-evaluation must include the fracture toughness of the beltline material and thus RT_{NDT} will be re-evaluated too. By that time, a number of plants will have credible surveillance data of their own. If not, and if Revision 2 of Reg. Guide 1.99 were used, RT_{NDT} values would be higher for a few vessels having high-nickel welds but most would be slightly lower.

If the calculative procedures of Revision 2 were substituted for those of the PTS Rule, and *if* the present information about copper, nickel, and fluence values is confirmed by the submittals required by paragraph (b) of Section 50.61 of the PTS Rule, it appears that eight plants would reach the screening criterion before EOL. Of the eight plants, three would reach the screening criterion in the year 1993 and four in the year 2000 or later. One plant would reach the screening criterion in 1987 if the presently used upper-bound values of copper and nickel apply, but it is understood that there is an effort underway to justify actual copper and nickel contents from a study of fabrication records. Based on these findings, it is recommended that the copies of proposed Revision 2 sent to each PWR owner be accompanied by a letter containing the following recommendation.

> The calculative procedures given in the proposed Revision 2 of Regulatory Guide 1.99 do not supersede the formula for RT_{PTS} given in the PTS Rule. However, it is possible that the PTS Rule will someday be amended to update those formulas. If so, the amended formula probably will yield results that are closer to those of Revision 2 than to those given by the PTS Rule. Therefore, it is recommended that licensees recalculate reference temperatures for their PWR reactor vessels, using the procedures of Revision 2, to see if further effort is warranted to enhance flux reduction and to verify copper, nickel, and fluence values for the critical material in the beltline.

4.b.2 Impact on Material Selection

For plants in the very early construction phase before the reactor vessel materials have been ordered, for which the provisions of Position C.3 of the Guide are applicable, the new procedure for calculating RT_{NDT} may have some effect on the limit specified for copper content. (Position C.3 itself is unchanged from Revision 1). However, sample calculations indicate that there should not be many instances of a negative effect, because they are made for end-of-life fluences.

For plants for which the surveillance materials have not been selected, the changes from Rev. 1 to Rev. 2 may affect the decision as to which beltline materials will be controlling and therefore which weld and base metal should be represented in the surveillance capsules. However, because we are not changing this requirement, there should not be any extra cost involved.

4.c. Constraints

We have not identified any constraints such as scheduling or enforceability that affect the implementation of Revision 2.

5. DECISION RATIONALE

Based on the foregoing analyses of the safety issues, system impacts and costs, it is recommended that Revision 2 be issued for public comment. The analysis has shown that the Guide is needed, because it provides part of the basis for ensuring safe operation of reactors during startup and shutdown and for the evaluation of transients and flaws found in service. Periodic updating of the Guide is consistent with the requirements of Appendix G, 10 CFR Part 50.

Adoption of Revision 2 will raise the P-T limits for about half of the operating reactors that now use Revision 1 as the basis for these limits. In preparing the value/impact analysis, based on contract work by PNL, one source of avoided risk by going to Revision 2 was quantified. After making corrections based on staff comments, the cost-benefit ratio was in the range $900-1400 per man-rem avoided. However, there is another, more significant source of risk which was not quantifiable. As discussed in Section 4.a.1.2, the principal safety impact of operating with lower P-T limits (i.e., continuing to use limits based on Revision 1) will occur during a transient, because the operator (a) will not have accurate information of the potential hazard to vessel integrity, and (b) will have less time to take corrective action. In paragraphs 4.a.1.4 and 4.a.1.5, reasons have been given to believe that the amount of replacement power, which is the principal cost impact of implementing Revision 2, will be lower for most plants than the values determined in the PNL cost estimates. In summary, it is believed that the cost benefit ratio is in the range of a few hundred

dollars per man-rem avoided. Because there is a significant safety benefit, and because it is cost effective, the implementation of Revision 2 is recommended.

Finally, we believe that industry will be receptive to the proposed "trend curves," as they are commonly called. Based on industry response to presentations to ASTM Committee E-10, the Metal Properties Council, and ASME Boiler Code Section XI working groups concerned with this subject, there appears to be general agreement on the need for new curves. At this time we know of no serious objection to the calculative procedures given in Revision 2. There may be disagreements about the chemistry factor or fluence factor near the edges of the data base, where extrapolation is required, and about the margin to be added. We intend to push for adoption in ASTM Standard Guide E900 as well as in Section XI of the ASME Boiler Code, but this will take at least a year or longer. If implementation of Rev. 2 is delayed, there will most likely be more negative ballots by those who expect to be impacted by the new trend curves. There will continue to be a need for Regulatory Guide 1.99 to provide acceptable treatment of the question of margin, the treatment of plant specific surveillance data, and the calculation of attenuation of damage through the vessel wall.

Further revision of Regulatory Guide 1.99 is to be expected. In Revision 2, Position C.1.b. and Figure 2, which presents a "trend curve" for the percent decrease in upper shelf energy as a function of fluence and copper content, needs to be upgraded when the basis becomes available in a year or so. That effort will not affect P-T limits and it will affect only relatively few plants--those having low upper shelf energy initially. Further adjustment of the calculative procedure for reference temperature may be indicated in a few years when more surveillance data have accumulated or when our understanding of embrittlement mechanisms and the role of copper, nickel and other elements improves.

6. IMPLEMENTATION

Paragraph D.1. of the Implementation Section of Revision 2 reads much as it did for Revision 1, the key sentence being: "...the methods described in regulatory position C.1 and C.2 will be used in evaluating all predictions of radiation damage needed to implement General Design Criterion 31 or as called

for in Appendices G and H to 10 CFR Part 50 submitted after the effective date of publication of the Guide." This means that plants will be allowed to continue to follow the present schedule for updating their P-T limits, but only within a 3-year period. Paragraph D.2. requires all operating plants to review the limits within a 3-year period after the Guide becomes effective and to revise them if necessary. The decision to forego prompt implementation across the board is based on the existence of significant margins, as discussed in Section 2.a.1 and elsewhere in this analysis. In the staff's judgment, the risk of allowing some plants to operate three more years with present P-T limits was justified by the reduced impact on the industry and the NRC achieved by not requiring a complete review of all P-T limits in a 6-12 month period. No staff actions will be required to implement the Guide other than making sure that each facility gets a copy.

7. OTHER IMPACTS

There are no other actions, systems or prior analyses known to need reassessment as a result of publication of Revision 2.

This Guide does not add to the reporting or information collection requirements of licensees, nor does it affect small entities as defined in the Regulatory Flexibility Act.

TABLE 1. SUMMARY OF THE CHANGES IN PRESSURE-TEMPERATURE LIMITS EXPECTED TO RESULT FROM A CHANGE FROM REVISION 1 TO REVISION 2 OF REGULATORY GUIDE 1.99

Effect of Change	Operating Reactors			Plants Undergoing Licensing		
from Rev. 1 to Rev. 2	PWR	BWR	Total	PWR	BWR	Total
Ratchet 50-100°	4*	4	8			
Ratchet 20-50°	16	17	33	32	12	44
No Change (±20°)	23	7	30	3	0	3
Benefit 20-50°	7	1	8			
Benefit 50-100°	1	0	1			
Benefit 100-150°	1	0	1			
Totals	52	29	81	35	12	47

*Values in the table are number of plants.

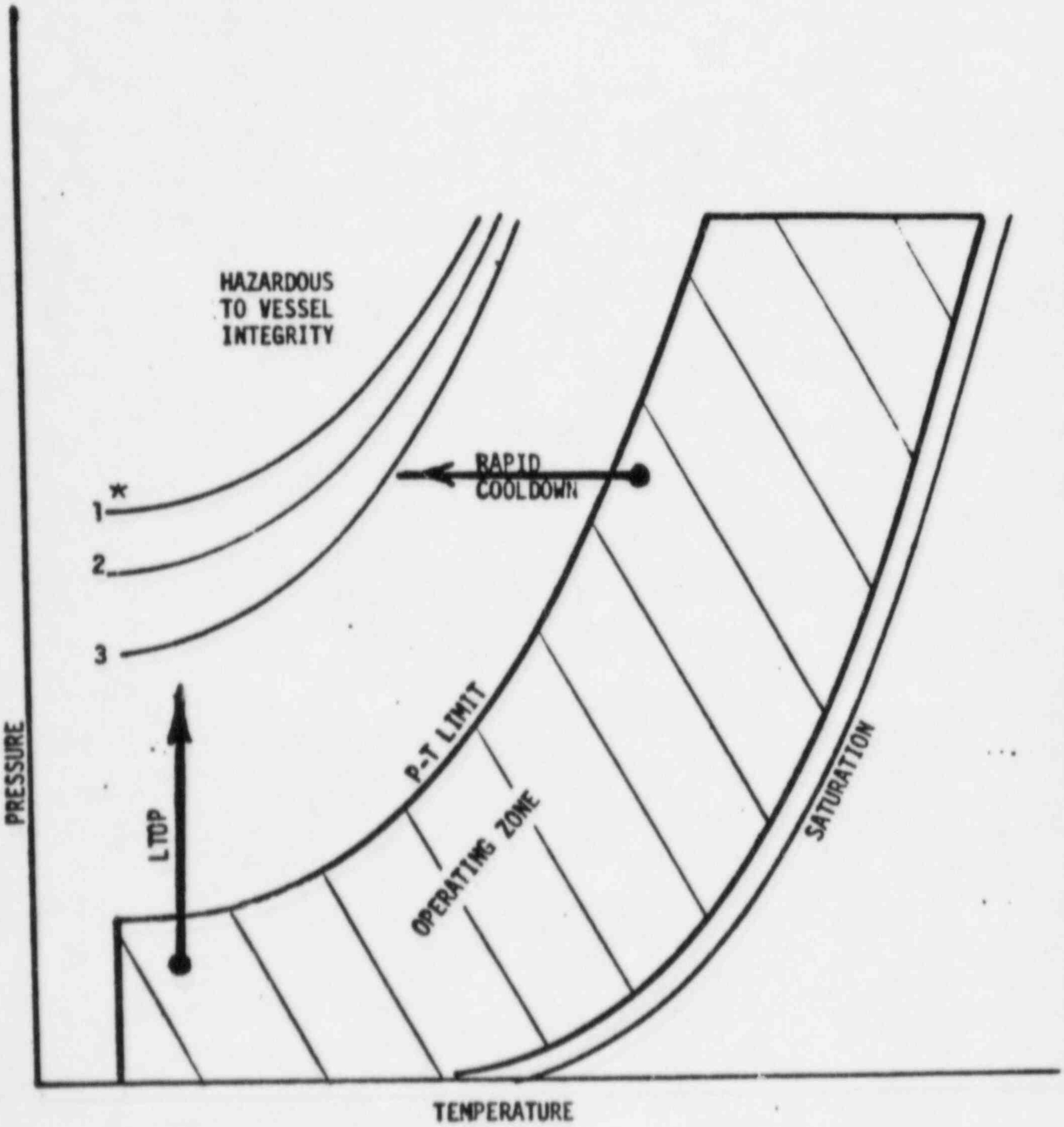

FIGURE 1 SCHEMATIC PRESSURE-TEMPERATURE DIAGRAM

*Note: The three curves represent different cooling rates, Curve 1 being the slowest.

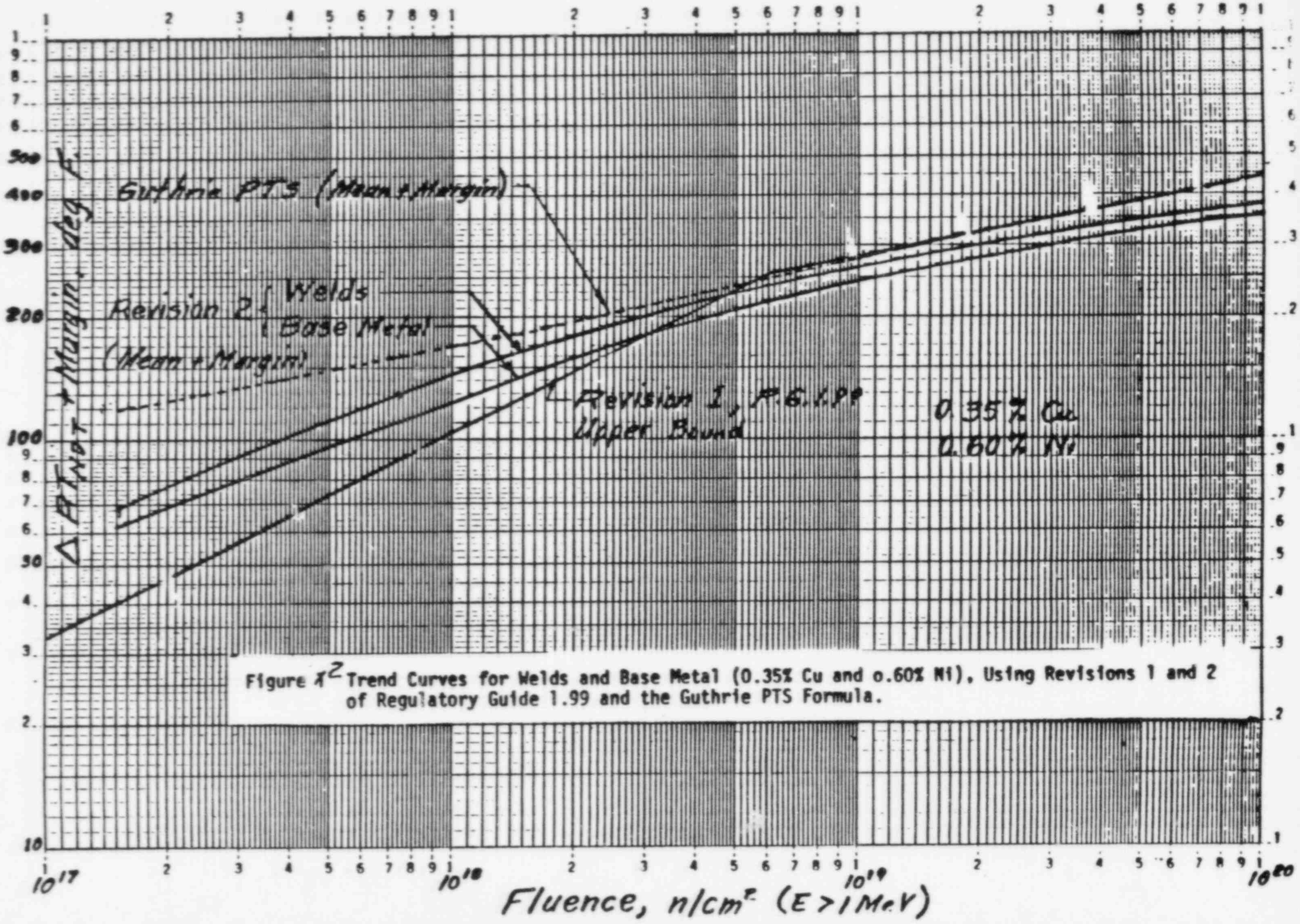

Figure 2 Trend Curves for Welds and Base Metal (0.35% Cu and o.60% Ni), Using Revisions 1 and 2 of Regulatory Guide 1.99 and the Guthrie PTS Formula.

Figure 3. WELDS

DIFFERENCE : Revision 2 of R.G. 1.99 minus Revision 1

Copper, Percent	0.2 % Nickel							0.6 % Nickel							1.0 % Nickel						
	10^{18}	2×10^{18}	5×10^{18}	10^{19}	2×10^{19}	5×10^{19}	10^{20}	10^{18}	2×10^{18}	5×10^{18}	10^{19}	2×10^{19}	5×10^{19}	10^{20}	10^{18}	2×10^{18}	5×10^{18}	10^{19}	2×10^{19}	5×10^{19}	10^{20}
0.05	21	29	38	38	29	-9	-60	37	51	68	64	52	17	-31	37	51	68	64	52	17	-31
0.10	29	38	47	41	20	-32	-99	77	89	97	98	88	48	-12	77	97	108	111	104	66	7
0.15	29	38	32	10	-28	-117	-228	46	81	82	72	46	-30	-34	95	107	118	117	99	33	-66
0.20	29	35	13	-20	-75	-185	-229	66	67	58	36	-9	-107	-144	92	103	109	99	66	-18	-48
0.25	31	25	-5	-48	-118	-154	-195	56	53	35	2	-59	-84	-120	84	91	89	69	21	10	-18
0.30	29	14	-24	-78	-94	-126	-165	49	41	14	-30	-37	-59	-92	75	77	65	33	38	29	3
0.35	22	4	-41	-59	-68	-95	-132	40	29	-5	-15	-16	-34	-65	65	63	42	45	55	50	26
0.40	31	16	-25	-38	-43	-66	-100	48	40	9	4	7	-7	-36	72	72	55	61	74	73	50

Notes

1. Units are degrees F
2. Revision 2 values are the mean plus 2σ, in order to be comparable to the upper bound values of Revision 1.

Figure 4 BASE METAL

DIFFERENCE : Revision 2 of R.G. 1.99 minus Revision 1

Copper, Percent	0.2 % Nickel							0.6 % Nickel							1.0 % Nickel						
	10^{18}	2×10^{18}	5×10^{18}	10^{19}	2×10^{19}	5×10^{19}	10^{20}	10^{18}	2×10^{18}	5×10^{18}	10^{19}	2×10^{19}	5×10^{19}	10^{20}	10^{18}	2×10^{18}	5×10^{18}	10^{19}	2×10^{19}	5×10^{19}	10^{20}
0.05	7	9	8	2	-14	-57	-109	7	9	8	2	6	-57	-109	7	9	8	2	-14	-57	-109
0.10	23	30	24	12	-10	-64	-130	29	35	29	19	-2	-54	-120	31	36	31	21	1	-51	-117
0.15	25	22	7	-16	-55	-145	-256	39	39	31	14	-19	-103	-211	42	43	36	21	-11	-93	-200
0.20	19	12	-11	-44	-100	-210	-254	39	39	27	3	-44	-144	-182	45	47	39	18	-26	-123	-160
0.25	13	3	-27	-70	-60	-176	-217	34	31	13	-20	-89	-106	-142	48	49	39	12	-43	-61	-93
0.30	7	-8	-46	-100	-116	-148	-187	27	19	-8	-52	-59	-81	-114	50	51	37	3	6	-4	-31
0.35	0	-18	-63	-81	-90	-117	-154	18	7	-28	-37	-38	-56	-87	43	41	20	23	33	28	4
0.40	9	-6	-47	-60	-65	-88	-122	26	18	-13	-18	-15	-29	-58	50	50	33	39	52	51	28

Notes

1. Units are degrees F
2. Revision 2 values are the mean plus 2σ, in order to be comparable to the upper bound values of Revision 1.

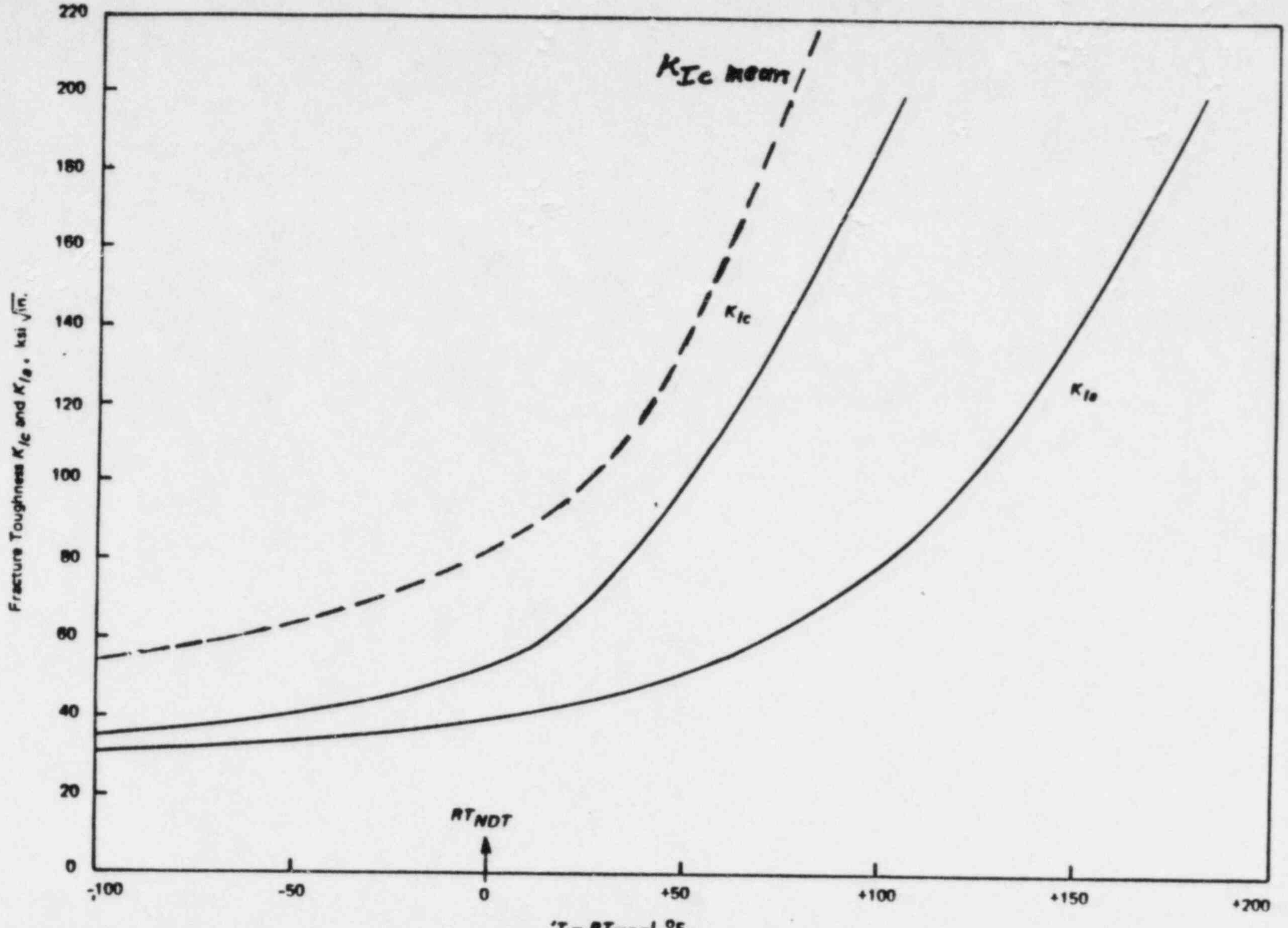

FIG. A-4200-1 LOWER BOUND K_{Ia} AND K_{Ic} TEST DATA FOR SA-533 GRADE B CLASS 1, SA-508 CLASS 2, AND SA-508 CLASS 3 STEELS

FIGURE 5 REFERENCE TOUGHNESS CURVES FROM SECTION XI OF THE ASME CODE. THE K_{Ia} CURVE IS THE SAME AS THE K_{IR} CURVE FROM SECTION III, APPENDIX G.