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H. B. ROBINSON STEAM ELECTRIC PLANT, UNIT NO. 2
DOCKET NO. 50-261 / RENEWED LICENSE NO. DPR-23

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION ASSOCIATED WITH RELIEF REQUEST (RR)-11 FOR RELIEF FROM VOLUMETRIC/SURFACE EXAMINATION FREQUENCY REQUIREMENTS OF ASME CODE CASE N-729-1

REFERENCES:

1. Letter from W. R. Gideon (Duke Energy Progress) to U. S. Nuclear Regulatory Commission (USNRC) (Serial: RNP-RA/14-0092), *Relief Request (RR)-11 for Relief from Volumetric/Surface Examination Frequency Requirements of ASME Code Case N-729-1,* dated August 27, 2014, ADAMS Accession No. ML14251A014
2. Letter from Martha Barillas (USNRC) to Site Vice President, H. B. Robinson Steam Electric Plant (Duke Energy Progress), *H. B. Robinson Steam Electric Plant, Unit 2 – Request for Additional Information Regarding Relief Request – 11 for Relief from Volumetric/Surface Examination Frequency Requirements of ASME Code Case N-729-1 (TAC No. MF4801),* dated October 28, 2014, ADAMS Accession No. ML14294A587

Dear Sir/Madam:

By letter dated August 27, 2014 (Reference 1) pursuant to 10 CFR 50.55a(a)(3)(i), Duke Energy Progress, Inc. requested relief from the requirements of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section XI, associated with the examination frequency requirements of Code Case N-729-1 at H. B. Robinson Steam Electric Plant, Unit No. 2 (HBRSEP2). This letter proposed an alternative examination requirement for the Reactor Vessel Top Head Penetration Nozzles.

During the review of the request, the NRC determined that additional information was needed to complete the review. On October 28, 2014 the NRC requested additional information regarding the relief request (Reference 2). Enclosed is the Duke Energy Progress response to the requested additional information.

Please address any comments or questions regarding this matter to Mr. Richard Hightower, Manager – Nuclear Regulatory Affairs at (843) 857-1329.

A047
NRR

There are no new regulatory commitments made in this letter.

Sincerely,

R. Michael Glover
Site Vice President

RMG/jmw

Enclosure

cc: Mr. V. M. McCree, NRC, Region II
Ms. Martha C. Barillas, NRC Project Manager, NRR
NRC Resident Inspector, HBRSEP2
Ms. S. E. Jenkins, Manager, Infectious and Radioactive Waste Management Section (SC)

H. B. ROBINSON STEAM ELECTRIC PLANT, UNIT NO. 2, RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION ASSOCIATED WITH RELIEF REQUEST (RR)-11 FOR RELIEF FROM VOLUMETRIC/SURFACE EXAMINATION FREQUENCY REQUIREMENTS OF ASME CODE CASE N-729-1

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION (RAI) REGARDING

RELIEF REQUEST (RR)-11 FOR RELIEF FROM VOLUMETRIC/SURFACE

EXAMINATION FREQUENCY REQUIREMENTS OF ASME CODE CASE N-729-1

DUKE ENERGY

DOCKET NUMBER 50-261

(TAC NO. MF4801)

By letter dated August 27, 2014 (Agencywide Documents Access and Management System (ADAMS) Accession Number ML14251A014), Duke Energy (the licensee) requested relief from the requirements of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI, associated with the examination frequency requirements of Code Case N-729-1 at H.B. Robinson, Unit 2. The licensee proposed an alternative examination requirement for the Reactor Vessel Top Head Penetration Nozzles as documented in Relief Request (RR)-11. To complete its review, the Nuclear Regulatory Commission staff requested the following additional information (ADAMS Accession Number ML14294A587).

RAI 1

The licensee uses Materials Reliability Program (MRP) 375, "Technical Basis for Reexamination Interval Extension for Alloy 690 PWR [Pressurized-Water Reactor] Reactor Vessel Top Head Penetration Nozzles," to provide a technical basis for the proposed alternative. With regards to MRP-375, Figures 3-1, 3-3, and 3-5, provide a brief description of the materials tested for each plot that have data points above a hypothetical 5. 7 factor of improvement line necessary to support the licensee's proposed alternative.

Response to RAI 1

Brief descriptions of the data points above a hypothetical 5.7 factor of improvement (FOI) line are provided below. As discussed in Section 3 of EPRI Materials Reliability Program report MRP-375 [1], a conservative approach was taken in MRP-375 to develop the FOI values describing the primary water stress corrosion cracking (PWSCC) crack growth rates applicable to Alloy 690 reactor vessel (RV) top head penetration nozzles. The crack growth rate data points presented in Figures 3-1, 3-3, and 3-5 of MRP-375 represent the values reported by individual researchers, without any adjustment by the authors of MRP-375 other than to normalize for the effect of temperature. The data in these figures represent essentially all of the data points reported by the various laboratories. No screening process was applied to the data on the basis of test characteristics such as minimum required crack extension or minimum required extent of transition along the crack front to intergranular cracking. Instead, an inclusive process was applied to conservatively assess the factors of improvement apparent in the data for specimens with less than 10% added cold work.

The approach was conservative in that no effort was made to screen out data points reflecting tests that are not applicable to plant conditions. Instead the data were treated on a statistical basis in Figures 3-2, 3-4, and 3-6 of MRP-375,[1] and compared to the crack growth rate variability due to material variability for Alloy 600 in MRP-55 [2] and Alloy 182 in MRP-115 [3]. A comparison between the cumulative distributions of the crack growth rates for Alloys 690/52/152 and Alloys 600/82/182 treats the full variability in both original and replacement alloys, rather than comparing the variability of the replacement alloy against a conservative mean (75th percentile) growth rate for the original alloys. By considering the cumulative distributions, a fuller perspective of the improved resistance of Alloys 690/52/152 emerges where over 70% of the data in each of Figures 3-2, 3-4, and 3-6 of MRP-375 indicate a factor of improvement beyond 20 and all of the data[2] correspond to a factor of improvement of 12 or greater. As described below, nearly all of the data points for the conditions directly relevant to plant conditions (e.g., constant load conditions) fall a factor of 5.7 times below the deterministic MRP-55 and MRP-115 equations.

A hypothetical 5.7 factor of improvement line in Figures 3-1, 3-3, and 3-5 of MRP-375 is not necessary to support the proposed inspection interval alternative. The deterministic MRP-55 and MRP-115 crack growth rate equations were developed not to describe bounding crack growth rate behavior but rather reflect 75th percentile values of the variability in crack growth rate due to material variability. Twenty-five percent of the material heats (MRP-55) and test welds (MRP-115) assessed in these reports on average showed crack growth rates exceeding the deterministic equation values. Thus, the appropriate FOI comparisons are made on a statistical basis (e.g., Figures 3-2, 3-4, and 3-6 of MRP-375). Comparing the crack growth rate for Alloys 690/52/152 versus the deterministic crack growth rate lines in Figures 3-1, 3-3, and 3-5 of MRP-375 represents an unnecessary compounding of conservatisms. It should be noted that none of the data presented lies within a statistical FOI of 5.7 below the MRP-55 and MRP-115 distributions of material variability. The technical basis for the inspection requirements for heads with Alloy 600 nozzles ([4], [5], [6]) are based on the full range of crack growth rate behavior, including heat-to-heat (weld-to-weld) and within-heat (within-weld) material variability factors. Thus, the Re-Inspection Year (RIY) = 2.25 inspection interval developed for heads with Alloy 600 nozzles reflects the possibility of crack growth rates being many times higher than the deterministic 75th percentile values per MRP-55 and MRP-115. Nevertheless, as described below, nearly all of the data points for the conditions directly relevant to plant conditions (e.g., constant load conditions) fall below a line a factor of 5.7 times below the deterministic MRP-55 and MRP-115 equations.

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[1] Figures 3-2, 3-4, and 3-6 of MRP-375 show cumulative distribution functions of the variability in crack growth rate normalized for temperature and crack loading (i.e., stress intensity factor). Each ordinate value in the plots shows the fraction of data falling below the corresponding crack growth rate. Thus the cumulative distribution function has the benefit of illustrating the variability in crack growth rate for a standard set of conditions.

[2] Excluding invalid data points reflecting fatigue pre-cracking conditions as described below.

Data Points Above a Hypothetical 5.7 Factor of Improvement Line in Figure 3-1, 3-3, and 3-5 of MRP-375

- *Figure 3-1 of MRP-375.* Figure 3-1 shows the complete set of data points compiled by the EPRI Expert Panel at the time MRP-375 was completed for Alloy 690 specimens with less than 10% added cold work. The following points are within a factor of 5.7 below the MRP-55 deterministic crack growth rate for Alloy 600:
  - There are six points within a factor of 5.7 below the MRP-55 75^{th} percentile curve, out of a total of 75 points shown in Figure 3-1 of MRP-375.
  - These data represent test segments from three distinct Alloy 690 compact tension (CT) specimens that were all tested by Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT).
  - Two of the points are from specimen 9ARB1, comprised of Alloy 690 plate material, loaded to 37 $MPa(m)^{0.5}$, and tested at 340°C and 15 cc H_2/kg H_2O [7]. Both of these data are for the first half of segments that exhibited a crack growth rate that was an order of magnitude lower in the second half of the segment. A plot of crack growth rate versus crack-tip stress intensity factor (K) for the Alloy 690 data from MRP-375 for plate material tested by CIEMAT is provided here as Figure 1. These two points have minimal implications for the requested inspection interval extension for several reasons:
    - As illustrated in Figure 1 and subsequent figures using open symbols, one of the two points was generated under partial periodic unloading (PPU) conditions. As discussed below in "Data Most Directly Applicable to Plant Conditions," PPU conditions may result in accelerated crack growth rates that are not directly representative of plant conditions, especially for the case of alloys with relatively high resistance to environmental cracking like Alloy 690. The other data point obtained under constant load/K conditions is only slightly above the line representing a factor of 5.7 below the MRP-55 deterministic crack growth rate for Alloy 600.
    - U.S. PWRs operate with a dissolved hydrogen concentration per EPRI guidelines in the range of 25-50 cc/kg for Mode 1 operation. Testing at 15 cc/kg results in accelerated crack growth rates versus that for normal primary water due to the proximity of the Ni-NiO equilibrium line [3].
    - Specimens fabricated from Alloy 690 plate material are not as relevant to plant RV top head penetration nozzles as specimens fabricated from control rod drive mechanism (CRDM) nozzle material. CRDM nozzles in U.S. PWRs are fabricated from extruded pipe or bar stock material.
    - The wide variability in crack growth rate within even the same testing segment indicates that significant experimental variability exists. Thus, there is a substantial possibility that a limited number of elevated growth rate data points do not reflect the true characteristic behavior of the material tested.
  - The remaining four points are from specimens 9T5 and 9T6, comprised of Valinox material heat WP787 CRDM nozzle material that was cold worked by a 20% tensile elongation (9.1% thickness reduction), loaded to roughly 27 $MPa(m)^{0.5}$, and tested at 325°C and 35 cc H_2/kg H_2O [8]. The final data are contained in EPRI MRP-340, but have not been openly published. As discussed later in "Data for Alloy 690 Wrought Material Including Added Cold Work…," the addition of cold work may result in a material that is substantially more susceptible than the as-received material. The extent

of transition along the crack front to intergranular cracking for these data was extremely low (≤ 5%). A plot of crack growth rate versus K for the Alloy 690 data from MRP-375 for heat WP787 is provided here as Figure 2. As in Figure 1, there is significant growth rate variability within the data for the same heat of material. The median for the CIEMAT specimens is more than a factor of 12 below the MRP-55 curve. Three of the four points are for PPU testing; this method may accelerate growth beyond what would be expected for in-service components, as discussed later. Additionally, the Pacific Northwest National Laboratory (PNNL) data indicate that the specific laboratory that produces the data can significantly influence the reported growth rate, such that there is a substantial possibility that a small number of reported data points with relatively high crack growth rates from a single laboratory are not characteristic of the true susceptibility of a specific heat of Alloy 690 material.

- *Figure 3-3 of MRP-375.* Figure 3-3 shows the complete set of data points compiled by the EPRI Expert Panel at the time MRP-375 was completed for Alloy 690 heat affected zone (HAZ) specimens. The following points are within a factor of 5.7 below the MRP-55 deterministic crack growth rate for Alloy 600:
  - There are two points within a factor of 5.7 below the MRP-55 75^{th} percentile curve, out of a total of 34 points shown in Figure 3-3 of MRP-375. Both of the points are from PPU testing and appear to have had very little to no intergranular engagement.
  - The two points are from CIEMAT testing of specimens 19ARH1 and 19ARH2, comprised of welded Alloy 690 plate material, tested at 340°C and 15 cc H_2/kg H_2O, and loaded to roughly 37 MPa$(m)^{0.5}$ [7]. A plot of crack growth rate versus K for the Alloy 690 HAZ data from MRP-375 for plate material tested by CIEMAT is shown in Figure 3. As discussed later, the orders of magnitude difference between these two PPU points and the constant load testing for this HAZ is indicative of the substantial accelerating effect that PPU testing can have beyond what would be expected in service environments.

- *Figure 3-5 of MRP-375.* Figure 3-5 shows the complete set of data points compiled by the EPRI Expert Panel at the time MRP-375 was completed for Alloy 52 and 152 weld metal specimens. The following points are within a factor of 5.7 below the MRP-115 deterministic crack growth rate for Alloy 182:
  - There are six points within a factor of 5.7 below the MRP-115 75^{th} percentile curve, out of a total of 212 points shown in Figure 3-5 of MRP-375. Two of these points are not relevant to PWR conditions and should not be considered further, as discussed in the following bullets. The four relevant data are from ANL testing, and two of these are for PPU testing.
    - Two of the points, including the point closest to the MRP-115 curve, are for environmental fatigue pre-cracking test segments [11]. (Similarly, two of the data points more than a factor of 5.7 below the MRP-115 curve are for environmental fatigue pre-cracking test segments [11].) The status of these four data points, which are shown in black in Figure 4, as being fatigue pre-cracking test segments irrelevant to SCC conditions was clarified subsequent to publication of MRP-375.
  - The remaining four data points represent three specimens from Alloy 152 weld material (Special Metals heat WC04F6) that were tested by ANL at 320°C and 23 cc

H_2/kg H_2O and loaded to between 27 and 30 MPa(m)$^{0.5}$ ([12] and [13]). These Alloy 152 specimens came from welded plate material. A plot of crack growth rate versus K for the Alloy 152 data from MRP-375 for heat WC04F6 is provided here as Figure 4. Two of these points were for PPU conditions. The other two points were for constant load/K conditions, which are most directly relevant to plant conditions, but are located only slightly above the line representing a factor of 5.7 below the MRP-115 deterministic crack growth rate for Alloy 182. Figure 4 shows a very large variability in the crack growth rate reported by different laboratories for this heat of Alloy 152 weld material. Roughly one third the ANL data, all of the GE data, and all the PNNL data for this heat are for specimens from a single weld made by ANL, illustrating the role of experimental variability. A small number of elevated data points for a weld produced by a single laboratory may not be representative of the true material susceptibility.

Data Most Directly Applicable to Plant Conditions

As described above, Section 3 of MRP-375 took an inclusive approach to statistical assessment of the compiled data. A conservative approach was applied in which both constant load data and data under PPU conditions were plotted together. In addition, weld data reflecting various levels of weld dilution adjacent to lower chromium materials was included in the data for Alloys 52/152. An assessment of the crack growth rate data points most applicable to plant conditions is presented in Figure 5 through Figure 10. The assessment shows very few points located within a factor of 5.7 below the deterministic MRP-55 and MRP-115 lines, with all such points only slightly above the line representing a factor of 5.7:

- *Figure 5 for Alloy 690 with Added Cold Work Less than 10%.*
  - Only one of 55 points is within a factor of 5.7 below the MRP-55 deterministic crack growth rate for Alloy 600.
  - Figure 6 shows that the data are bounded by a FOI of more than 12 relative to Alloy 600 data on a statistical basis.
- *Figure 7 for Alloy 690 HAZ.*
  - None of the 24 points are within a factor of 5.7 below the MRP-55 deterministic crack growth rate for Alloy 600.
  - Figure 8 shows that the data are bounded by a FOI of more than 12 relative to Alloy 600 data on a statistical basis.
- *Figure 9 for Alloys 52/152.*
  - Only two of 83 points are within a factor of 5.7 below the MRP-115 deterministic crack growth rate for Alloy 182.
  - Figure 10 shows that the data are bounded by a FOI of more than 12 relative to Alloy 182 data on a statistical basis.

As discussed above, the technical basis for heads with Alloy 600 nozzles assumes the substantial possibility of crack growth rates substantially greater than that predicted by the deterministic equations of MRP-55 and MRP-115. The MRP-55 and MRP-115 deterministic crack growth rate equations are not bounding equations, but rather reflect the 75th percentile of material variability. Thus, the perspective provided in Figure 6, Figure 8, and Figure 10 is most relevant to drawing conclusions regarding FOI values applicable to inspection intervals for heads with nozzles fabricated using Alloy 690, 52, and 152 materials.

The data presented in Figure 5 through Figure 10 were included on the basis of the following considerations:

- As demonstrated and discussed in MRP-115, certain PPU conditions will act to accelerate the crack growth rate. PPU conditions, which include a periodic partial reduction in load, are often used in testing to transition from initial fatigue conditions toward constant load conditions with the crack in a state most representative of stress corrosion cracks if they had initiated in plant components over long periods of time. The periodic load reductions and accompanying load increases may rupture localized crack ligaments along the crack front, facilitating transition of the crack to an intergranular morphology. In MRP-115, data with hold times less than 1 hour were screened out of the database for Alloys 82/182/132. The greater resistance of Alloys 690/52/152 to cracking is expected to result in a greater sensitivity of the crack growth rate to partial periodic unloading conditions. Figure 11 and Figure 3 show that there is an apparent significant bias for the data for Alloy 690 in which the data for partial periodic unloading conditions are substantially higher than for constant load conditions. Thus, the data presented in Figure 5 through Figure 10 have been restricted to the constant load (or constant K) conditions that are most relevant to plant conditions for growth of stress corrosion cracks.

- The Alloy 52/152 weld metal data shown in Figure 3-5 and Figure 3-6 of MRP-375 include data reflecting a range of weld dilution levels. The data presented in Figure 9 and Figure 10 exclude the weld dilution data points. The weld dilution data are not reflective of the full chromium content of Alloy 52/152 weld metal.

- The data presented in Figure 9 and Figure 10 exclude a small number of data points that reflect cracking at the fusion line with carbon or low-alloy steel material. Some of these data reflect cracking in the adjacent carbon or low-alloy steel material that was not post-weld heat treated as would be the case in plant applications.

- The data presented in Figure 9 and Figure 10 eliminate the few data points that in fact reflect fatigue pre-cracking rather than stress corrosion cracking. The status of these data points was clarified subsequent to publication of MRP-375.

- As noted above, of the data most relevant to plant conditions, only three are located within a factor of 5.7 below the standard deterministic crack growth rate lines. The remaining point in Figure 5 that lies within a factor of 5.7 below the deterministic MRP-55 line represents only a small fraction of the data and is only slightly within the factor of 5.7. This data point is for a material form (i.e., plate material) not directly representative of reactor vessel head nozzle material, and was produced for a hydrogen concentration outside of the normal range for PWR operation. The two remaining points in Figure 9 that lie within a factor of 5.7 below the deterministic MRP-115 line represent only a small fraction of the data and are only slightly within the factor of 5.7. These two points represent specimens from two Alloy 152 test welds produced using filler material heat WC04F6 that were tested by ANL. The other data points produced by ANL for these two test welds are substantially lower.

The limited number of remaining points in Figure 5 and Figure 9 that lie within a factor of 5.7 below the deterministic MRP-55 and MRP-115 lines represent the upper end of material and/or experimental variability. Figure 6, Figure 8, and Figure 10 consider the variability in crack growth rate among different heats/welds of Alloys 600/82/182 and compare this against the full variability of the Alloy 690/52/152 data most applicable to plant conditions. The lack of *any* points within a factor of 12 when accounting for variability in Alloy 600/82/182 crack growth rates supports a reexamination interval longer than the requested interval corresponding to a FOI of 5.7. The volumetric or surface inspection interval for heads with Alloy 600 nozzles reflects consideration of crack growth rates on a statistical basis, with crack growth rates often higher than that given by the deterministic equations of MRP-55 and MRP-115.

<u>Data Specific to Argonne National Laboratory (ANL) and Pacific Northwest National Laboratory (PNNL)</u>

An assessment of the crack growth rate data points particular to data generated by ANL and PNNL is presented in Figure 12 through Figure 17, including data with up to 20% cold work. The data shown are specifically those data that have been openly published, representing the large majority of the data from ANL and PNNL in MRP-375. Since only two constant load Alloy 690 HAZ points have been openly published, the cumulative distribution of Figure 15 also includes data that have not been openly published. The data for ANL and PNNL are shown separately because U.S. NRC is most familiar with the testing performed at these two national laboratories. Only 2 of the total of 94 constant load (or constant K) data points from ANL and PNNL are within a factor of 5.7 below the deterministic MRP-55 and MRP-115 lines.

<u>Data for Alloy 690 Wrought Material Including Added Cold Work up to 20% for CRDM Nozzle and Bar Material Product Forms</u>

An assessment of the crack growth rate data points for Alloy 690 CRDM nozzle and bar material product forms for cold work levels up to 20% is presented in Figure 18 and Figure 19. Equivalent plots for Alloy 52/152 material for the purpose of including the limited number (i.e., five) of weld metal data points generated for added cold work conditions are shown in Figure 20 and Figure 21. Added cold work for weld metals is not directly relevant to plant material conditions.

For Alloy 690 control rod drive mechanism (CRDM) / control element drive mechanism (CEDM) nozzles and other RV head penetration nozzles, the effective cold-work level in the bulk Alloy 690 base metal is expected to be no greater than roughly 10%. This is based on fabrication practices specific to replacement heads, i.e., material processing and subsequent nozzle installation via welding [14]. Furthermore, the crack growth rate data presented for Alloy 600 in MRP-55 do not include cases of added cold work. Comparing cold worked Alloy 690 data against non-cold worked Alloy 600 data results in a conservatism in the factor of improvement for Alloy 690 material as the cold worked material condition for Alloy 600 would be expected to result in a somewhat increased deterministic crack growth rate for Alloy 600, and thus a greater apparent factor of improvement. Nevertheless, the assessment in Figure 18 through Figure 21 is included in this document to illustrate the effect of higher levels of cold work. These data show the potential for modestly higher crack growth rates for such elevated cold work levels for the material product forms most relevant to RV top head nozzles.

Based on the discussion above and the presentation of data in Figure 1 through Figure 21, it is shown that the factor of improvement for the replacement head materials is conservatively greater than that needed to justify the requested inspection deferral at H.B. Robinson Unit 2.

RAI 2

Provide any similarities between the items listed in (1) above and the associated nozzles and weld material used in the current reactor pressure vessel upper head at H. B. Robinson, Unit 2.

Response to RAI 2

As discussed below, there are not any relevant similarities between (a) the data points within a factor of 5.7 below the MRP-55 or MRP-115 line in Figure 3-1, 3-3, and 3-5 of MRP-375 and (b) the associated nozzles and weld material used in the current reactor pressure vessel upper head at H.B. Robinson Unit 2:

- *Figure 3-1 of MRP-375* [1]. The Alloy 690 nozzle material used in the head at Robinson 2 was supplied by Sumitomo Metal Industries. The ASTM/ASME material specification for the nozzle material is SB-167 UNS N06690, and the head was constructed to ASME Section III, 1998 Edition, 2000 Addenda. None of the Alloy 690 data points in Figure 3-1 of MRP-375 were produced for specimens of Alloy 690 CRDM nozzle material that was supplied by Sumitomo. Furthermore, there are no other similarities that indicate any specific concern for elevated PWSCC susceptibility of the head nozzles at H.B. Robinson Unit 2 in comparison to other heads with Alloy 690 nozzles.

- *Figure 3-3 of MRP-375* [1]. None of the Alloy 690 HAZ data points in Figure 3-3 of MRP-375 were produced for specimens of Alloy 690 CRDM nozzle material that was supplied by Sumitomo. Furthermore, there are no other similarities that indicate any specific concern for elevated PWSCC susceptibility of the head nozzles at H.B. Robinson Unit 2 in comparison to other heads with Alloy 690 nozzles. It is noted that the welding process used to produce the HAZ in the test specimens is not specific to any particular categories of replacement heads.

- *Figure 3-5 of MRP-375* [1]. There are no relevant similarities between (a) the Alloy 52 and 152 data points above a crack growth rate 5.7 times lower than the MRP-115 [3] Alloy 182 deterministic crack growth rate in Figure 3-5 of MRP-375 and (b) the Alloy 52/152 weld material used in the RV top head at H.B. Robinson Unit 2. The variability among test welds with respect to PWSCC crack growth susceptibility reflects a combination of how the weld was made (welding procedure, weld design, degree of constraint, etc.) and perhaps the material variability in the weld consumable (e.g., composition). The test welds used to produce the crack growth rate data compiled in MRP-375 are not identified with any particular fabricator of replacement RV heads. Furthermore, the weld specimens used in the crack growth rate testing were machined from test welds in flat plates, not from actual J-groove welds. Thus, the test weld specimens should not be associated with particular fabrication categories of replacement heads.

It is noted that the H.B. Robinson Unit 2 replacement RV head was procured from Mitsubishi Heavy Industries, LTD. The weld metals used were Unified Numbering System (UNS) N06052 / American Welding Society (AWS) ERNiCrFe-7 (Alloy 52 – Gas Tungsten Arc Welding (GTAW)) and UNS W86152 / AWS ENiCrFe-7 (Alloy 152 – Shielded Metal Arc Welding (SMAW)). The RV head manufacturer (i.e., welding organization) was Mitsubishi Heavy Industries, LTD.

Further Discussion of the Variability in Reported Laboratory Crack Growth Rates

Even though there are no relevant similarities between the nozzle and weld materials used in the Robinson 2 head and the crack growth rate data in MRP-375, it is emphasized that a small number of data points showing relatively high crack growth rates cannot readily be concluded to be characteristic of the true material behavior expected in the field:

- Most of the crack growth rate data for heats that had points within a factor of 5.7 below the MRP-55 deterministic curve or MRP-115 deterministic curve were substantially lower. Thus, the best-estimate behavior for every heat or test weld of material presented in Figures 3-1, 3-3, and 3-5 of MRP-375 reflects a factor of improvement substantially greater than 5.7. In addition, other factors being equal, one would expect a greater range of crack growth rates for a material heat for which a greater number of data points was produced. Some of the scatter likely reflects experimental uncertainty as opposed to true material variability. Experimental uncertainty is more of a factor for the data for Alloys 690/52/152 than for Alloys 600/82/182/132 considering the greater testing challenges associated with the more resistant replacement alloys.

- In some cases, different laboratories have reported large differences in crack growth rate for the same material heat or test weld. This behavior is illustrated in Figure 4 for the Alloy 152 heat WC04F6 and Figure 22 for the Alloy 690 heat WP142. Thus, individual data points showing relatively high crack growth rates might not reflect the true susceptibility of particular categories of nozzle or weld material. Consistent data from multiple laboratories may be needed before one can conclude that a particular category of nozzle or weld material has an elevated susceptibility to PWSCC growth.

The crack growth rate data compiled in MRP-375 [1] for Alloys 52 and 152 reflect the composition variants applicable to PWR plant applications. Data are included for the following variants: Alloy 52 (UNS N06052 / AWS ERNiCrFe-7), Alloy 52M (UNS N06054 / AWS ERNiCrFe-7A), Alloy 52MSS (UNS N06055 / AWS ERNiCrFe-13), Alloy 52i (AWS ERNiCrFe-15), Alloy 152 (UNS W86152 / AWS ENiCrFe-7), and Alloy 152M (UNS W86152 / AWS ENiCrFe-7). The H.B. Robinson Unit 2 head uses Alloy 52 (UNS N06052 / AWS ERNiCrFe-7) and Alloy 152 (UNS W86152 / AWS ENiCrFe-7). Considering the overall set of available crack growth rate data for the various variants of Alloy 52 and 152, there is no basis for concluding that the variants used at Robinson 2 are of specific concern for relatively high crack growth rates. Furthermore, there is no basis for concluding any significant difference in the average behavior exists between the Alloy 52 and Alloy 152 variants used at H.B. Robinson Unit 2.

In addition, it should be recognized that PWSCC of Alloy 690 RV head penetration nozzles or their Alloy 52/152 attachment welds is not an active degradation mode, with over 25 years of use in PWR environments. Some type of PWSCC initiation is necessary to produce a flaw that may grow via PWSCC. Laboratory and plant experience show that Alloys 690/52/152 are substantially more resistant to PWSCC initiation than Alloys 600/82/182 [1]. Thus, it is premature to single out individual materials or fabrication categories of heads with Alloy 690 nozzles for additional scrutiny on the basis of laboratory crack growth rate data. In the case of heads with Alloy 600 nozzles, for which PWSCC is an active degradation mode, materials and fabrication categories of heads with relatively high incidence of PWSCC are inspected in accordance with the same requirements as other heads.

Conclusion

Based on the additional information and discussion provided above, it is concluded that the available crack growth rate data clearly support a factor of improvement greater than 5.7 for the H.B. Robinson Unit 2 replacement head. The crack growth rate data do not indicate any susceptibility concerns specific to the nozzle or weld materials specific to the H.B. Robinson Unit 2 replacement head.

References

1. *Materials Reliability Program: Technical Basis for Reexamination Interval Extension for Alloy 690 PWR Reactor Vessel Top Head Penetration Nozzles (MRP-375)*, EPRI, Palo Alto, CA: 2014. 3002002441. [freely available at www.epri.com]
2. *Materials Reliability Program (MRP) Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Thick-Wall Alloy 600 Materials (MRP-55) Revision 1*, EPRI, Palo Alto, CA: 2002. 1006695. [freely available at www.epri.com]
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Data from Individual Heats

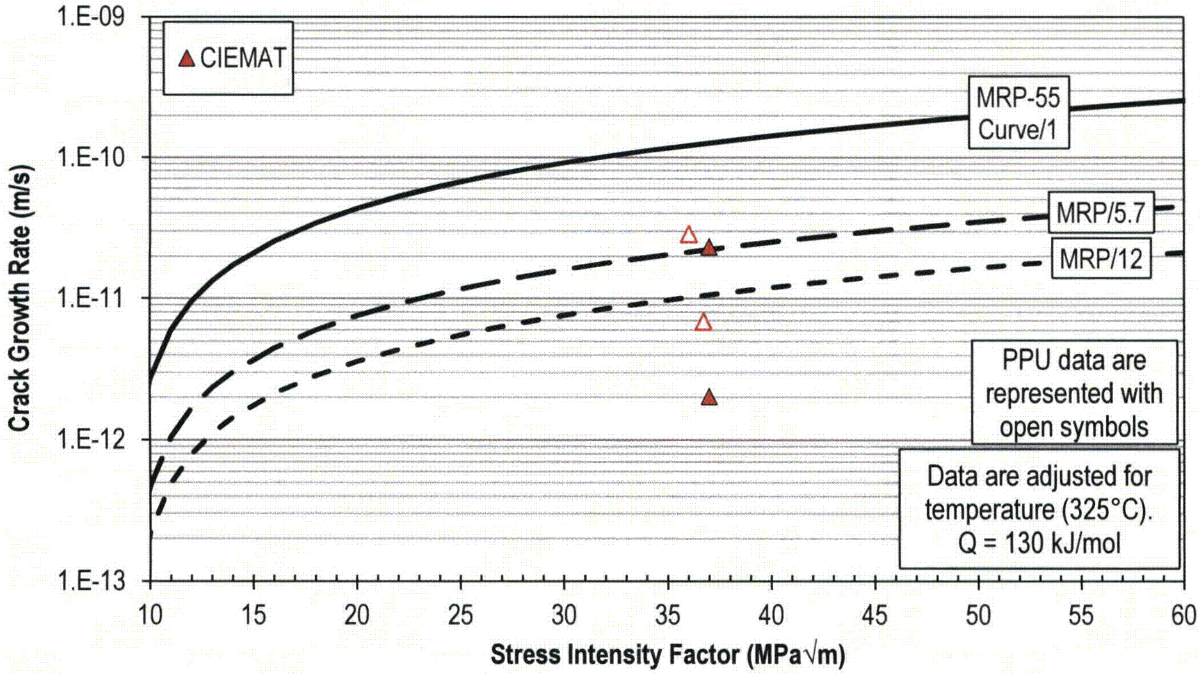

Figure 1. Plot of Crack Growth Rate (da/dt) versus Stress Intensity Factor (K_I) for Alloy 690 Data from Plate Material Tested by CIEMAT

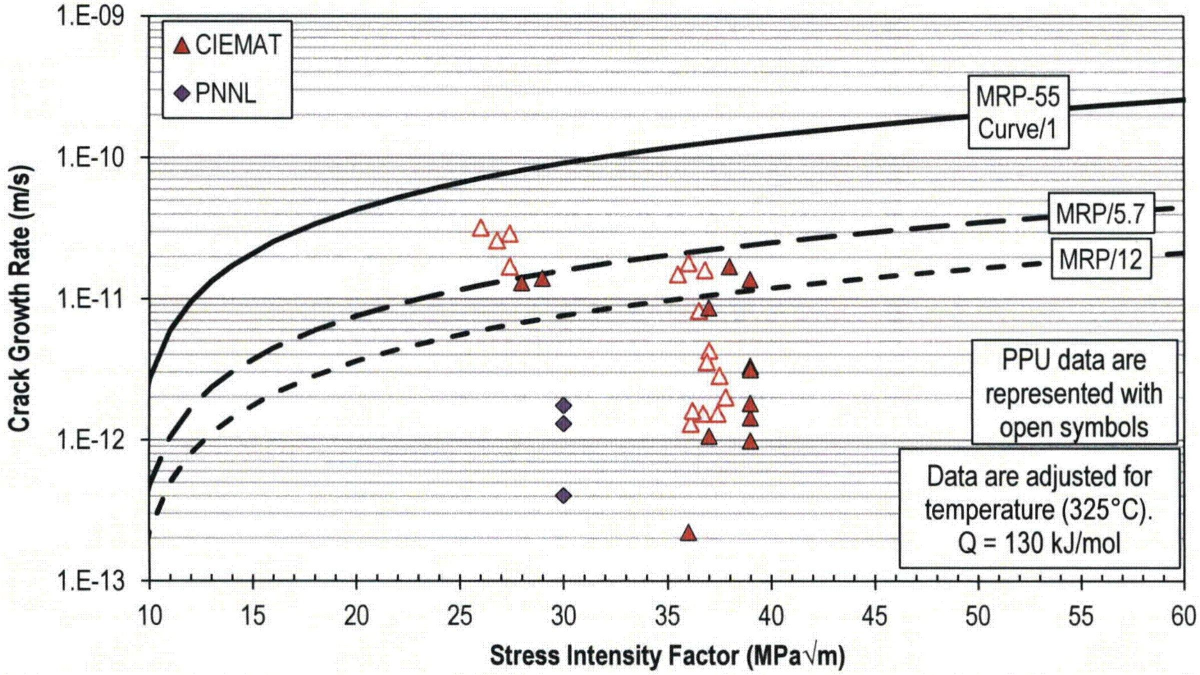

Figure 2. Plot of da/dt versus K_I for Alloy 690 Data from Heat WP787

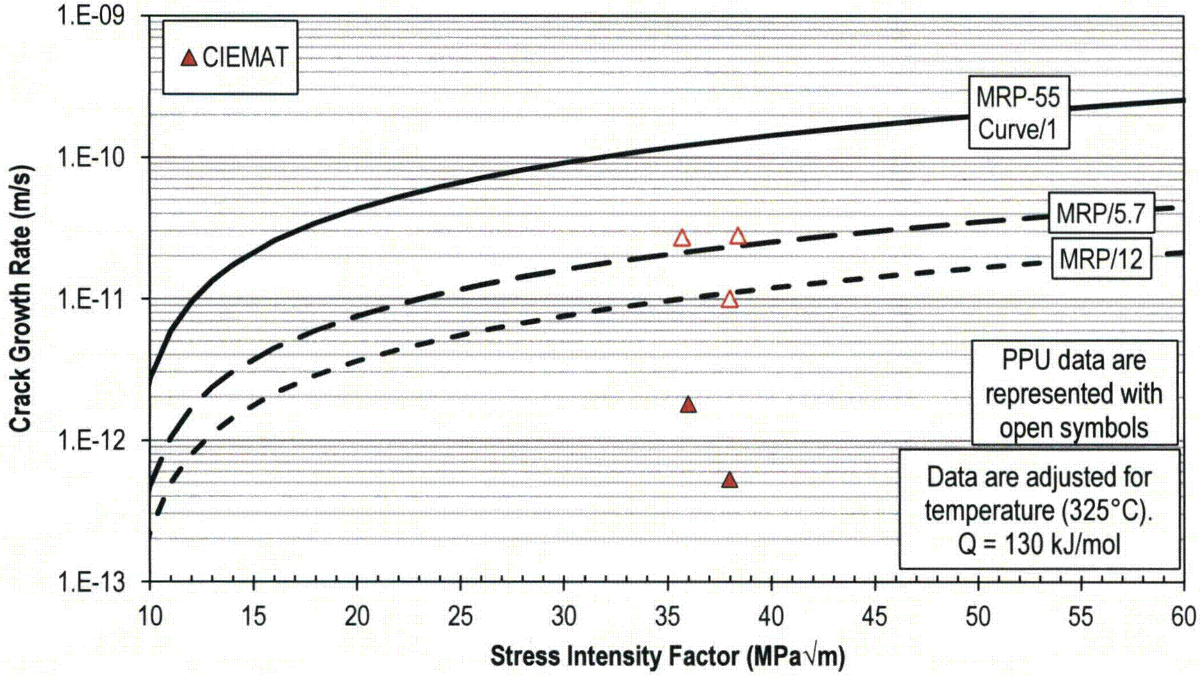

Figure 3. Plot of da/dt versus K_I for Alloy 690 HAZ Data from Plate Material Tested by CIEMAT

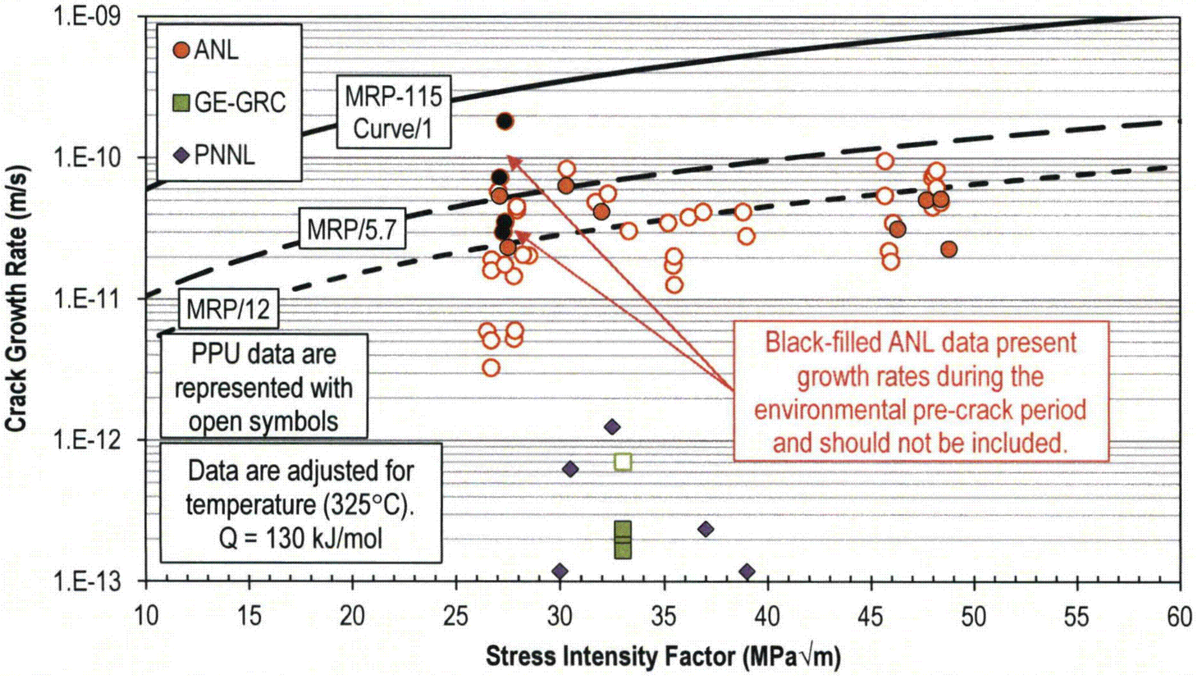

Figure 4. Plot of da/dt versus K_I for Alloy 152 Data from Heat WC04F6

Data Most Applicable to Plant Conditions

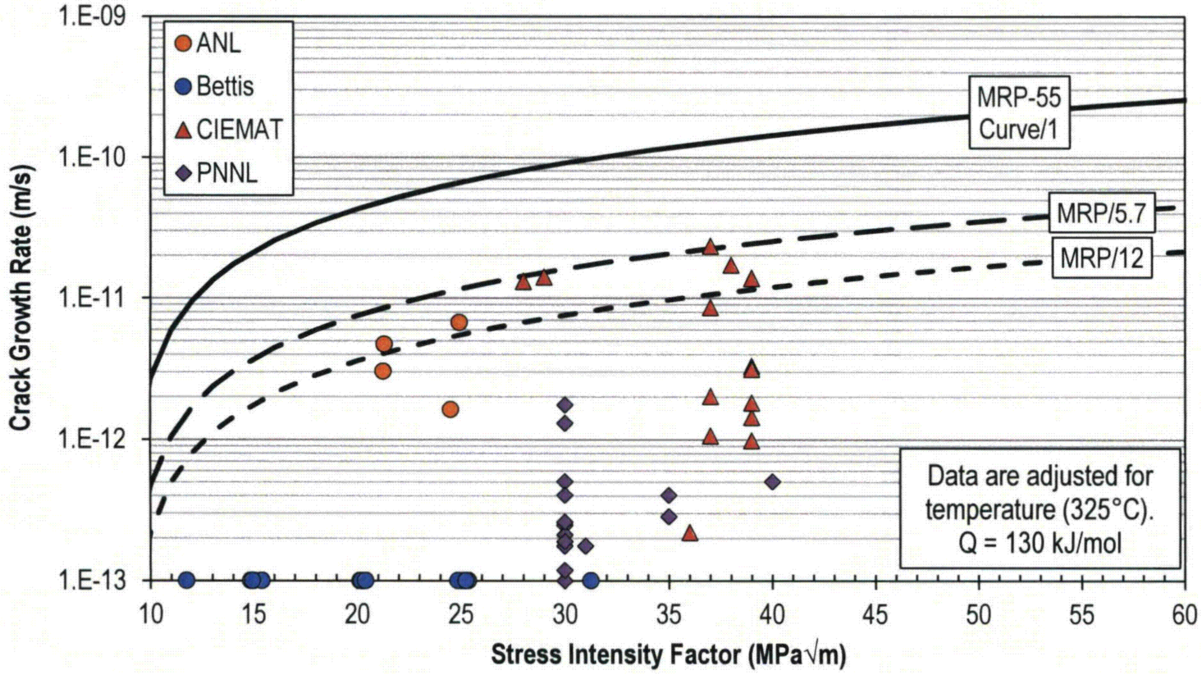

Figure 5. Plot of da/dt versus K_I for Alloy 690 Data from All Laboratories, ≤ 10% Cold Work, Constant Load or K_I

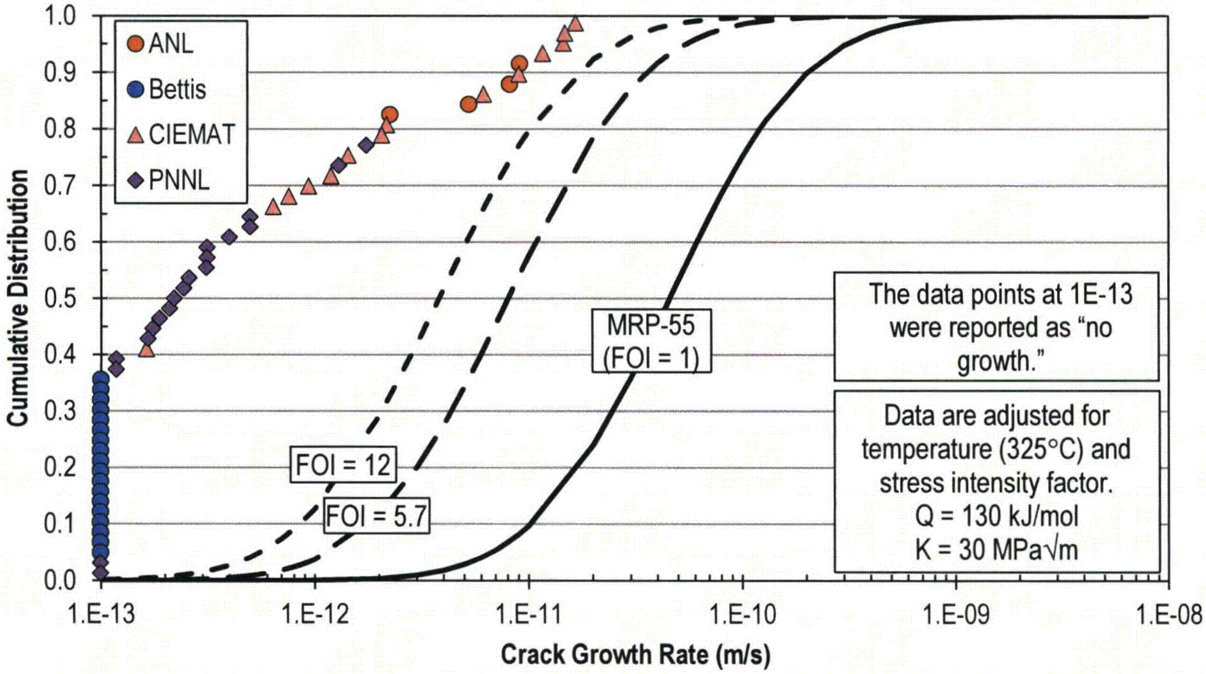

Figure 6. Cumulative Distribution Function of Adjusted da/dt for Alloy 690 Data from All Laboratories, ≤ 10% Cold Work, Constant Load or K_I

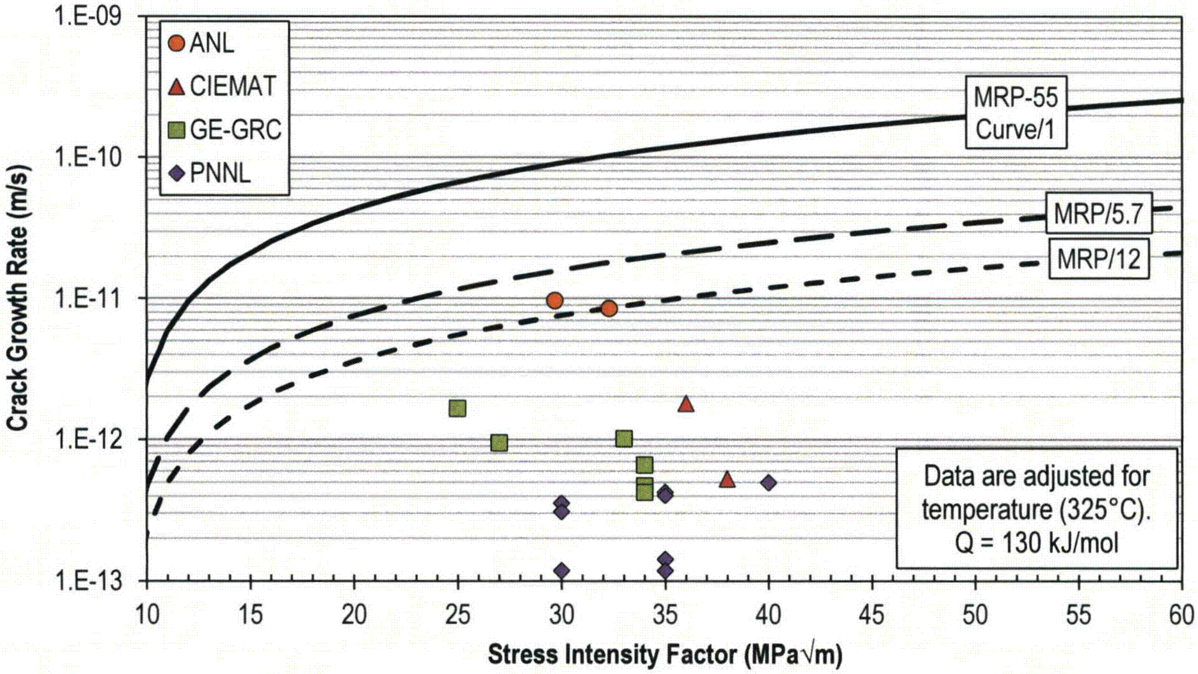

Figure 7. Plot of da/dt versus K_I for Alloy 690 HAZ Data from All Laboratories, ≤ 10% Cold Work, Constant Load or K_I

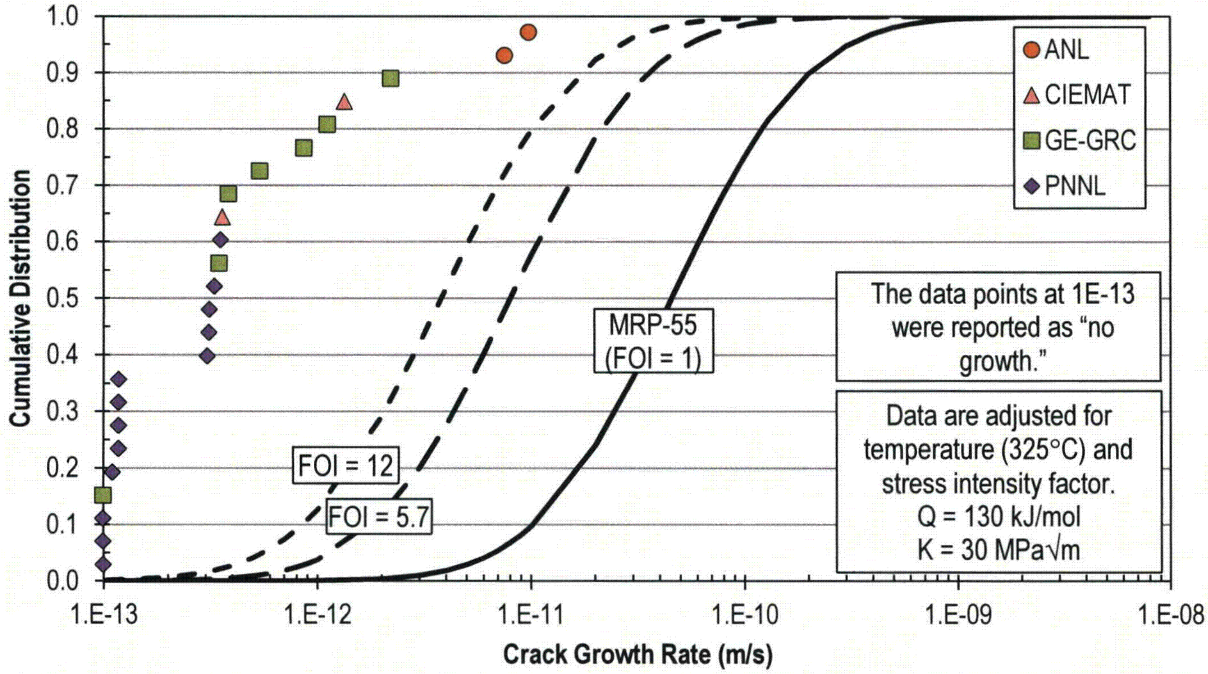

Figure 8. Cumulative Distribution Function of Adjusted da/dt for Alloy 690 HAZ Data from All Laboratories, ≤ 10% Cold Work, Constant Load or K_I

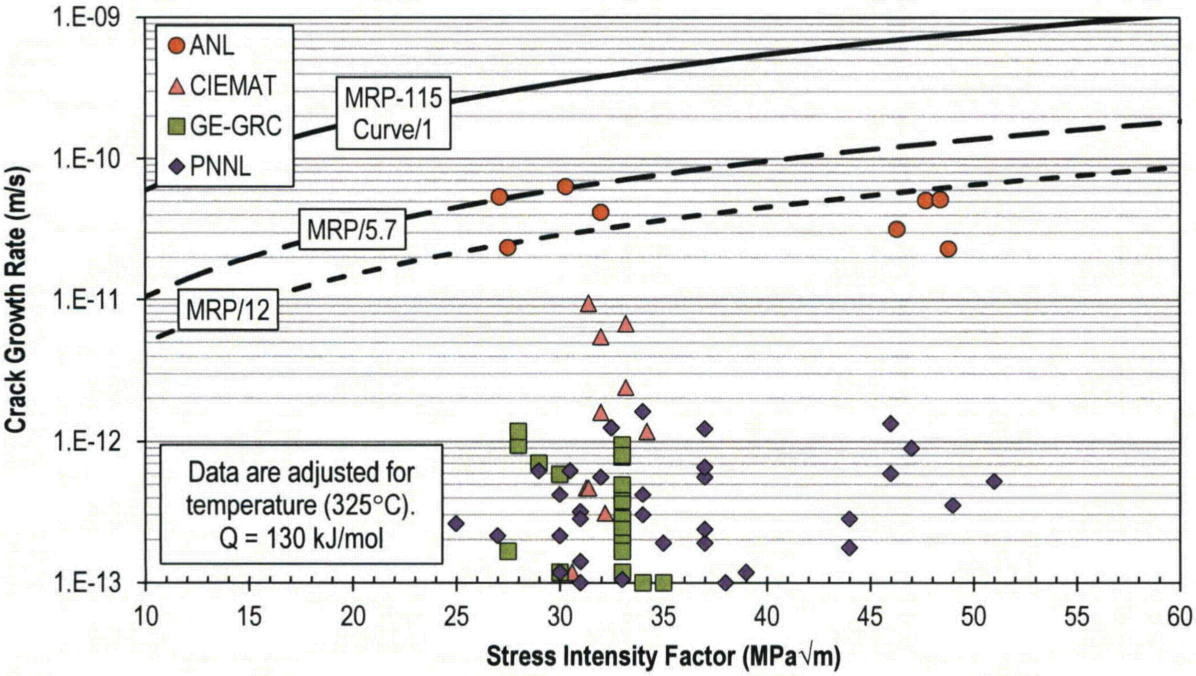

Figure 9. Plot of da/dt versus K_I for Alloy 52/152 Data from All Laboratories, ≤ 10% Cold Work, Constant Load or K_I

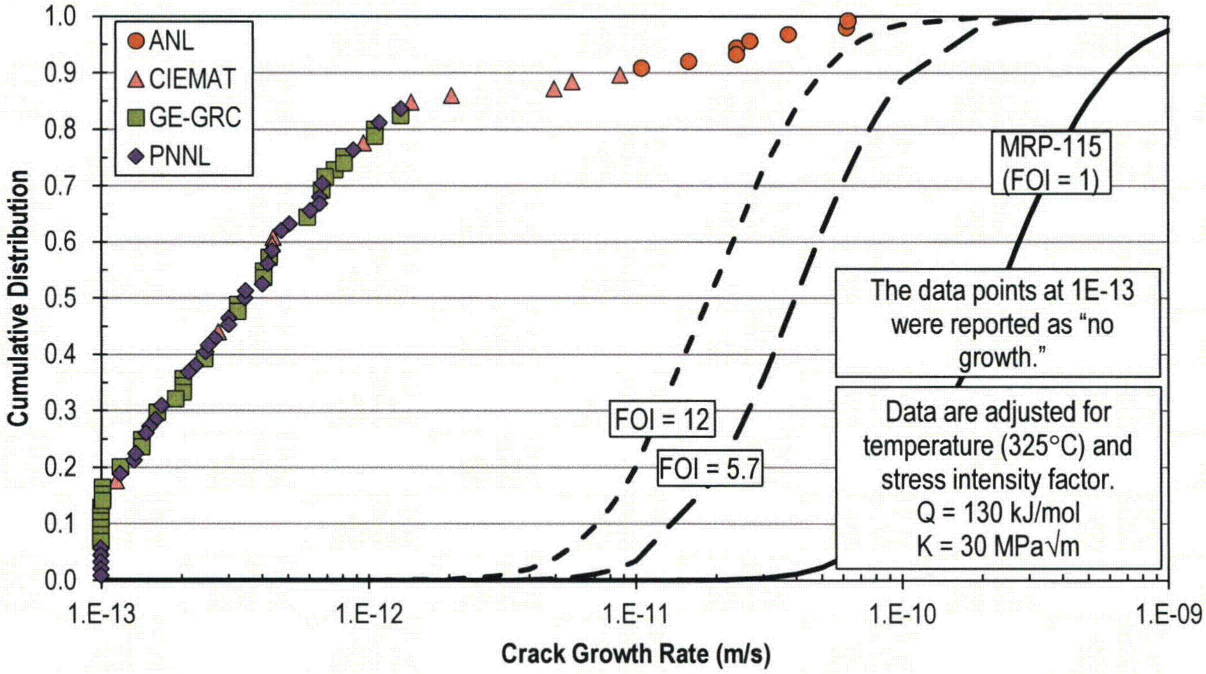

Figure 10. Cumulative Distribution Function of Adjusted da/dt for Alloy 52/152 Data from All Laboratories, ≤ 10% Cold Work, Constant Load or K_I

Comparison of Partial Period Unloading (PPU) Conditions vs. Constant Load Conditions

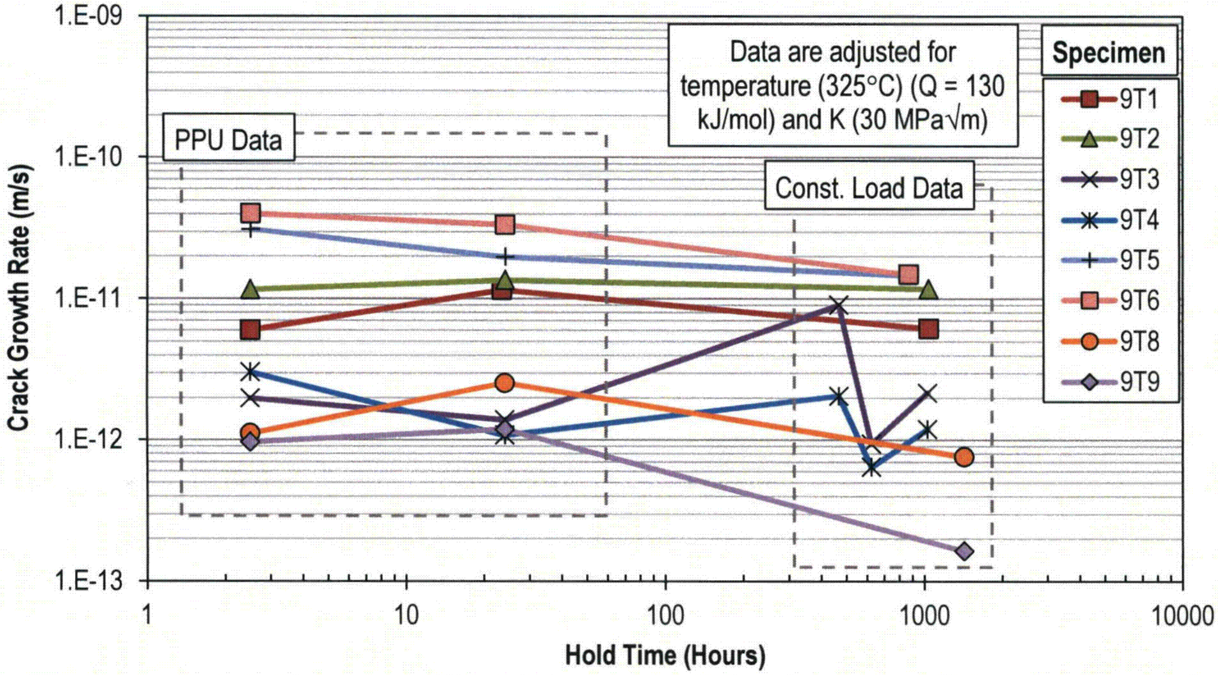

Figure 11. Plot of da/dt versus Loading Hold Time (for PPU testing) or Test Segment Duration (for Constant K_I/Load Testing) from Heat WP787

Compilation of ANL and PNNL Data

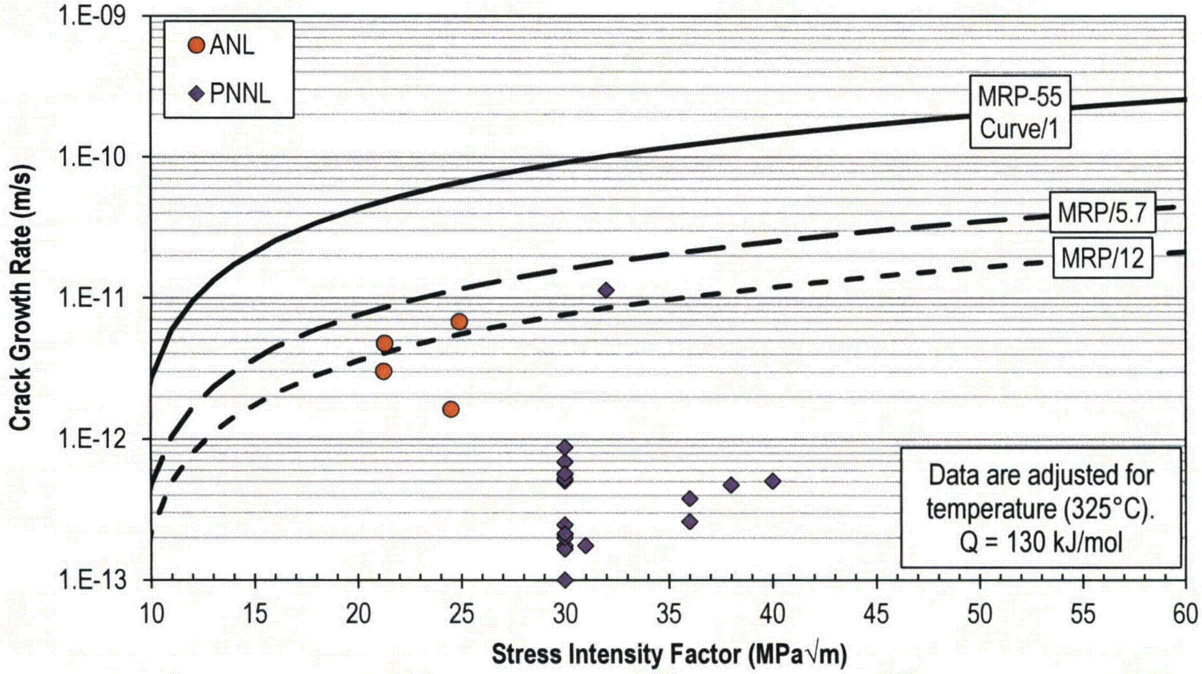

Figure 12. Plot of da/dt versus K_I for Alloy 690 Data Produced by ANL and PNNL and Available in Public References, ≤ 20% Cold Work

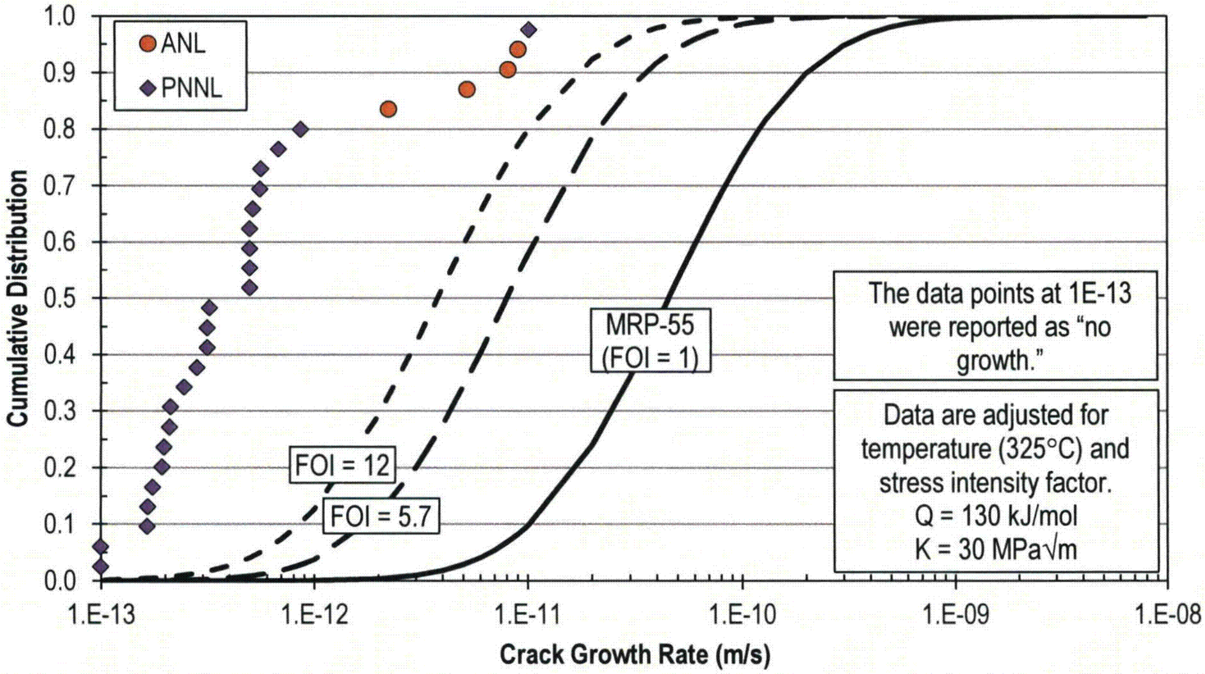

Figure 13. Cumulative Distribution Function of Adjusted da/dt Alloy 690 Data Produced by ANL and PNNL and Available in Public References, ≤ 20% Cold Work

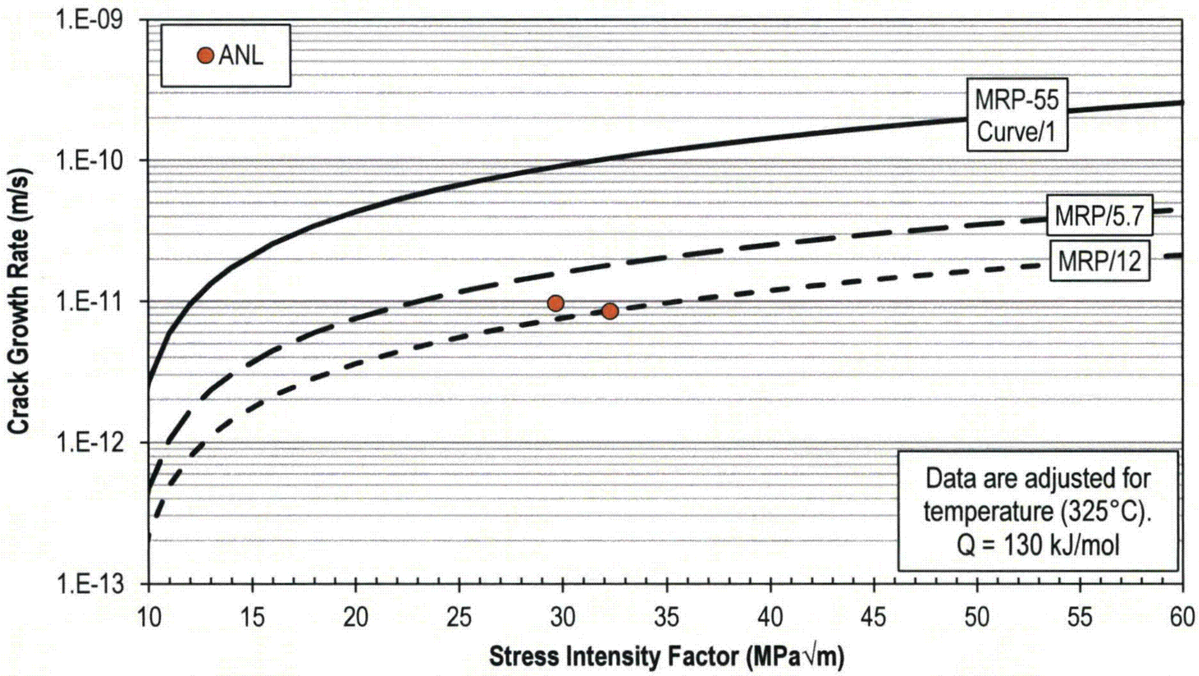

Figure 14. Plot of da/dt versus K_I for Alloy 690 HAZ Data Produced by ANL and PNNL and Available in Public References, ≤ 20% Cold Work

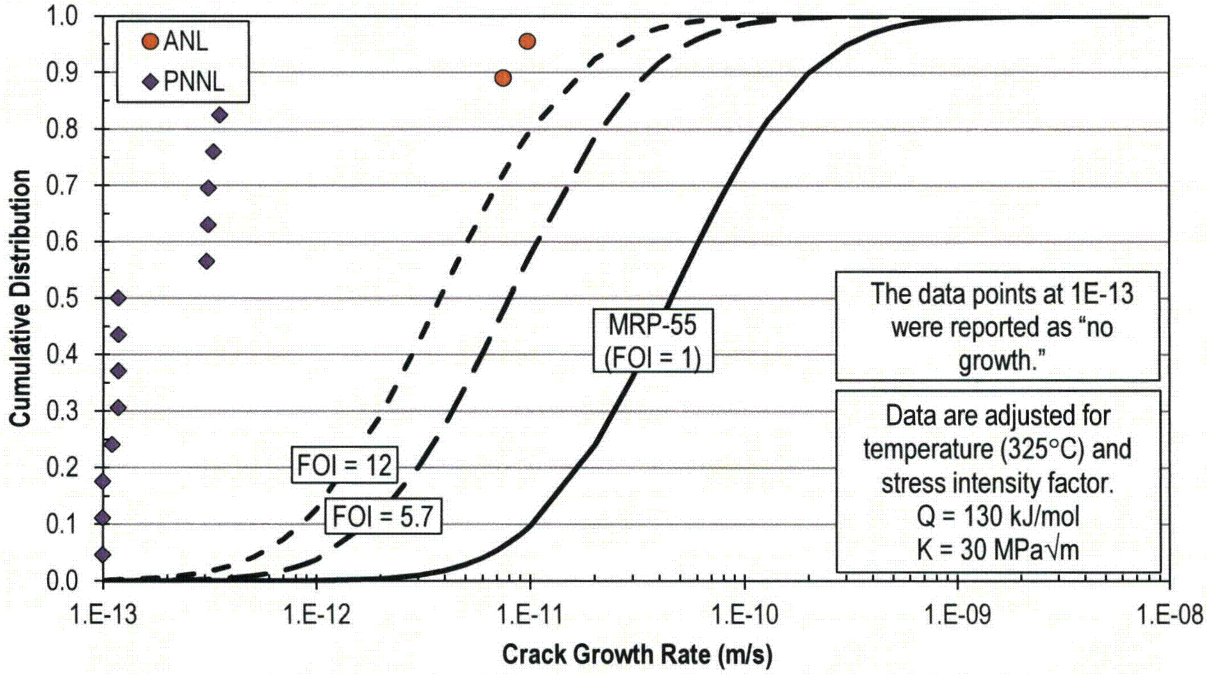

Figure 15. Cumulative Distribution Function of Adjusted da/dt Alloy 690 HAZ Data Produced by ANL and PNNL, Including Data Not Openly Published, ≤ 20% Cold Work

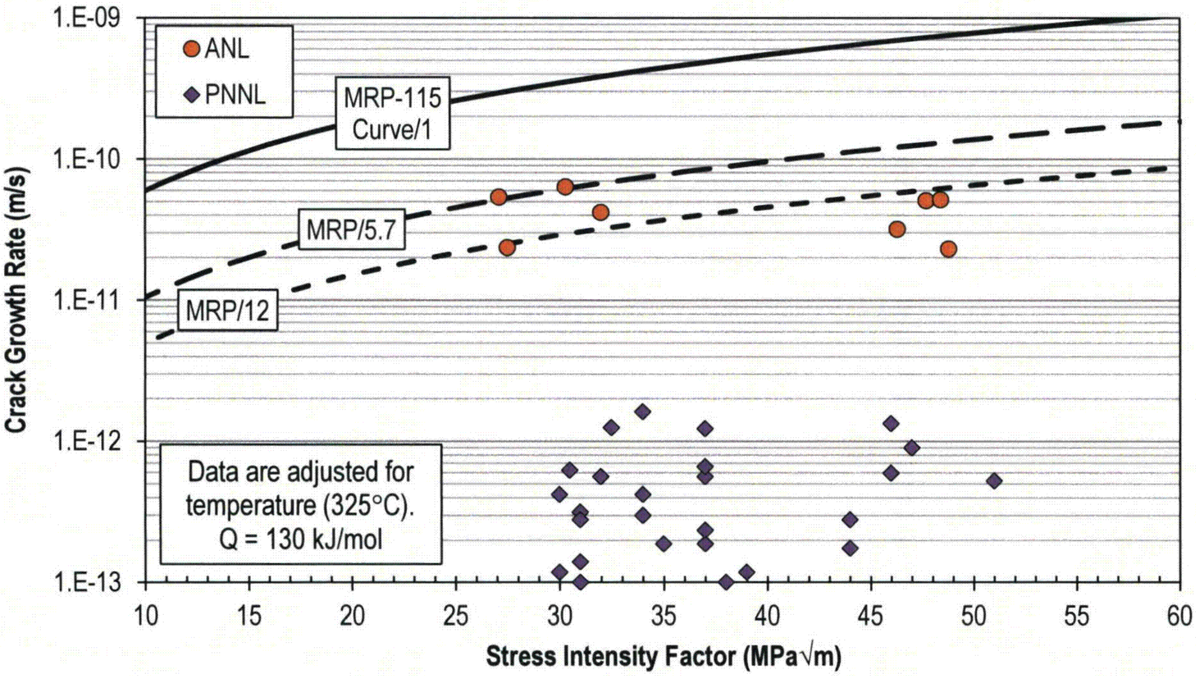

Figure 16. Plot of da/dt versus K_I for Alloy 52/152 Data Produced by ANL and PNNL and Available in Public References, ≤ 20% Cold Work

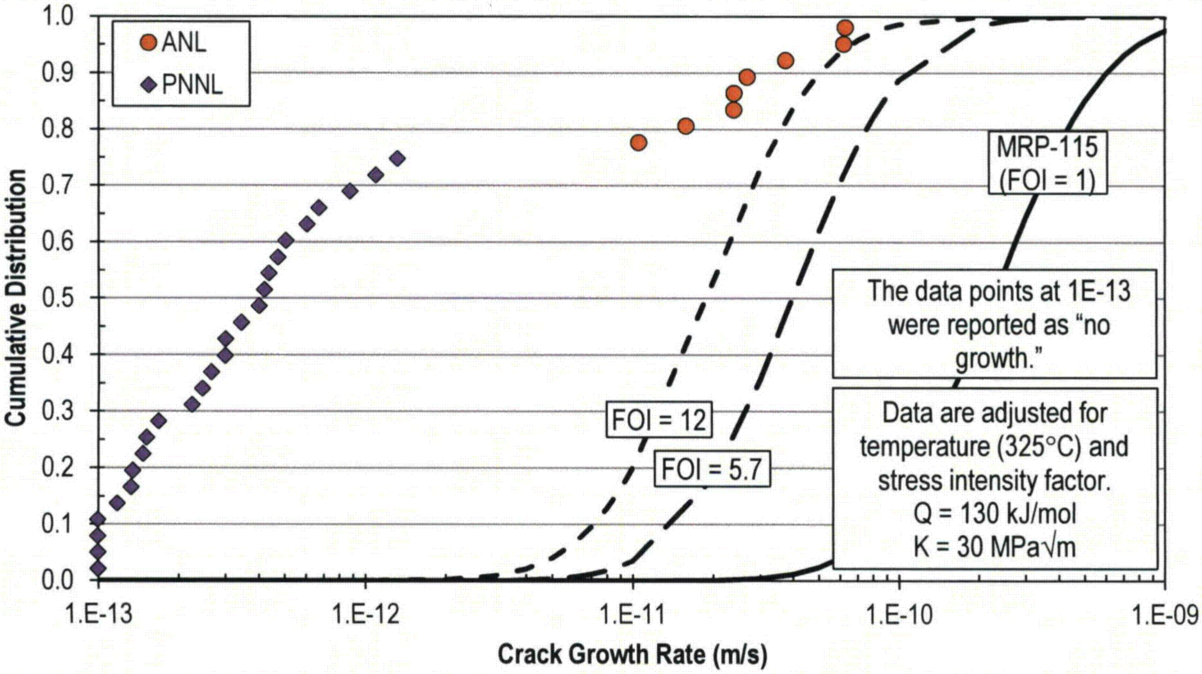

Figure 17. Cumulative Distribution Function of Adjusted da/dt Alloy 52/152 Data Produced by ANL and PNNL and Available in Public References, ≤ 20% Cold Work

Data for Less than 20% Cold Work from All Laboratories

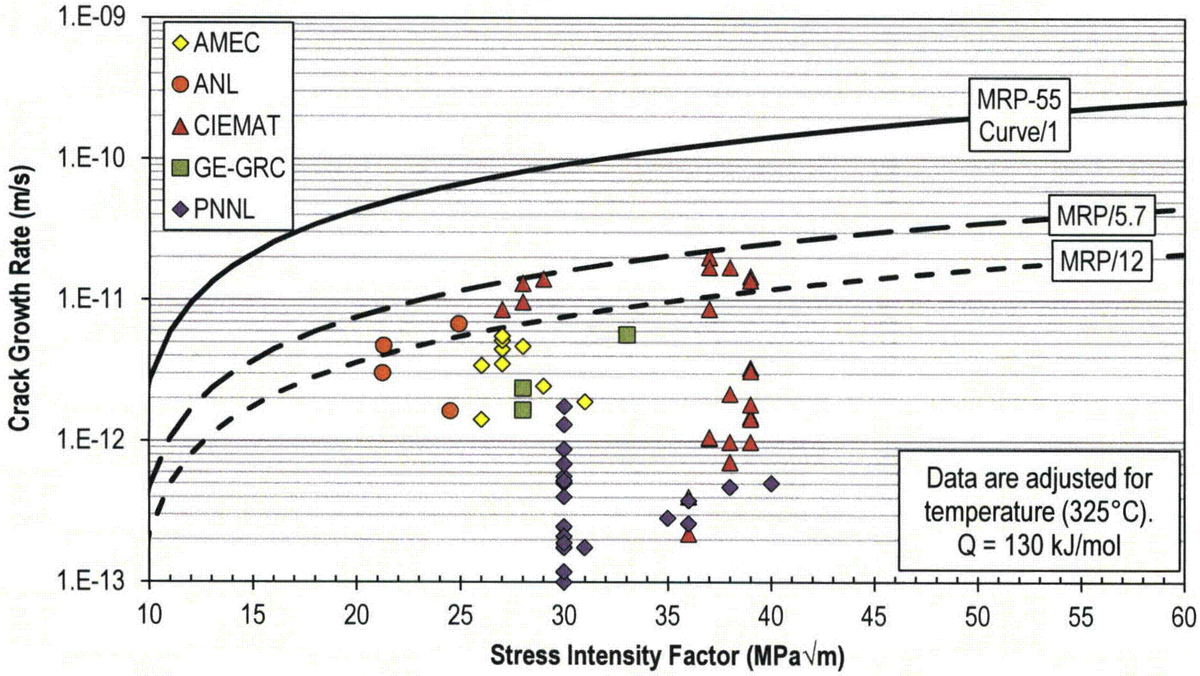

Figure 18. Plot of da/dt versus K_I for Alloy 690 Data from All Laboratories, > 10 & ≤ 20% Cold Work, CRDM and Bar Material, Constant Load or K_I Testing

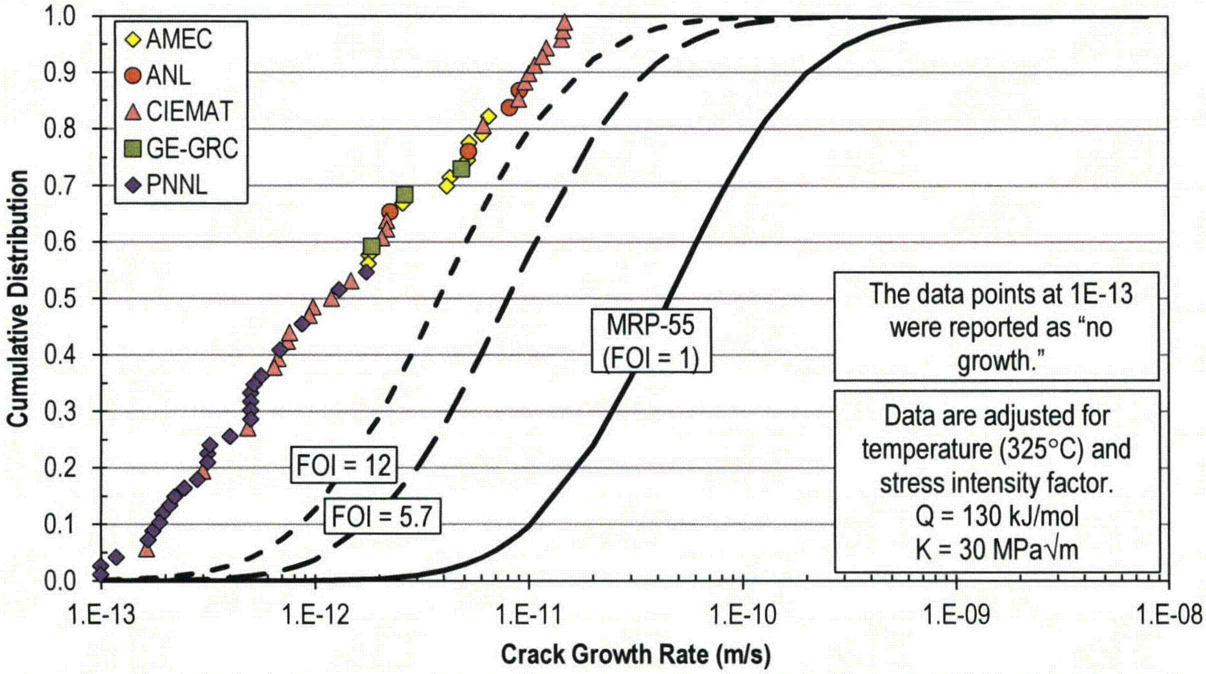

Figure 19. Cumulative Distribution Function of Adjusted da/dt Alloy 690 Data from All Labs, ≤ 20% Cold Work, CRDM and Bar Material, Constant Load or K_I

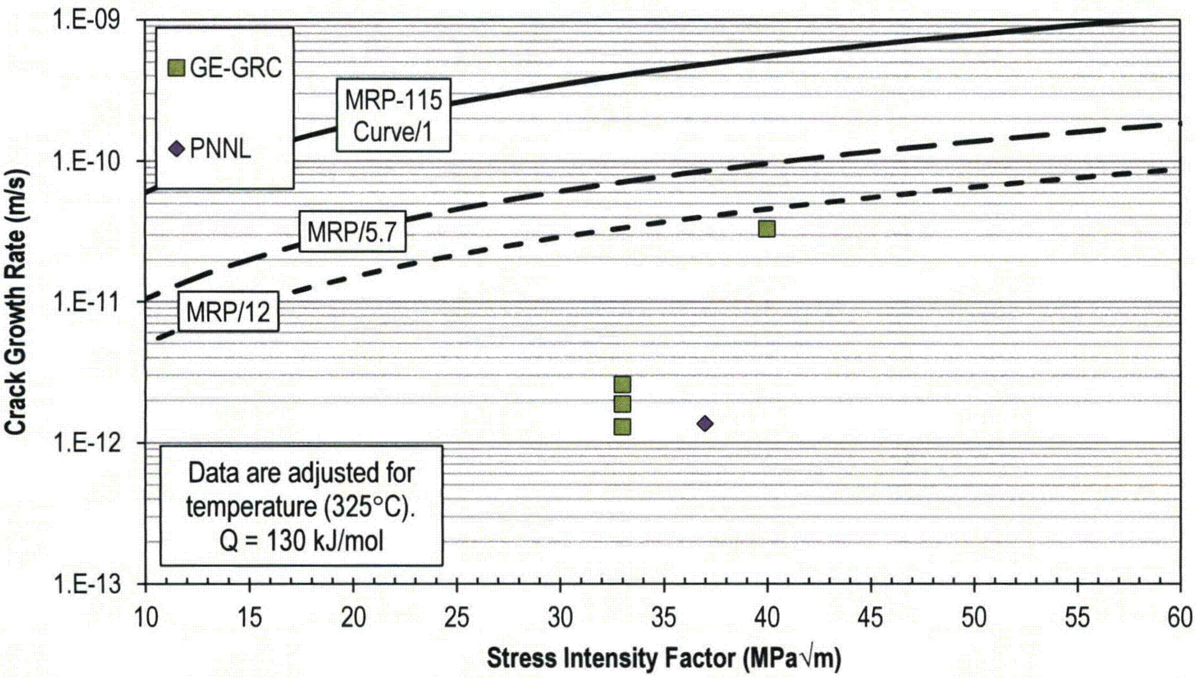

Figure 20. Plot of da/dt versus K_I for Alloy 52/152 Data from All Laboratories, > 10 & ≤ 20% Cold Work, Constant Load or K_I

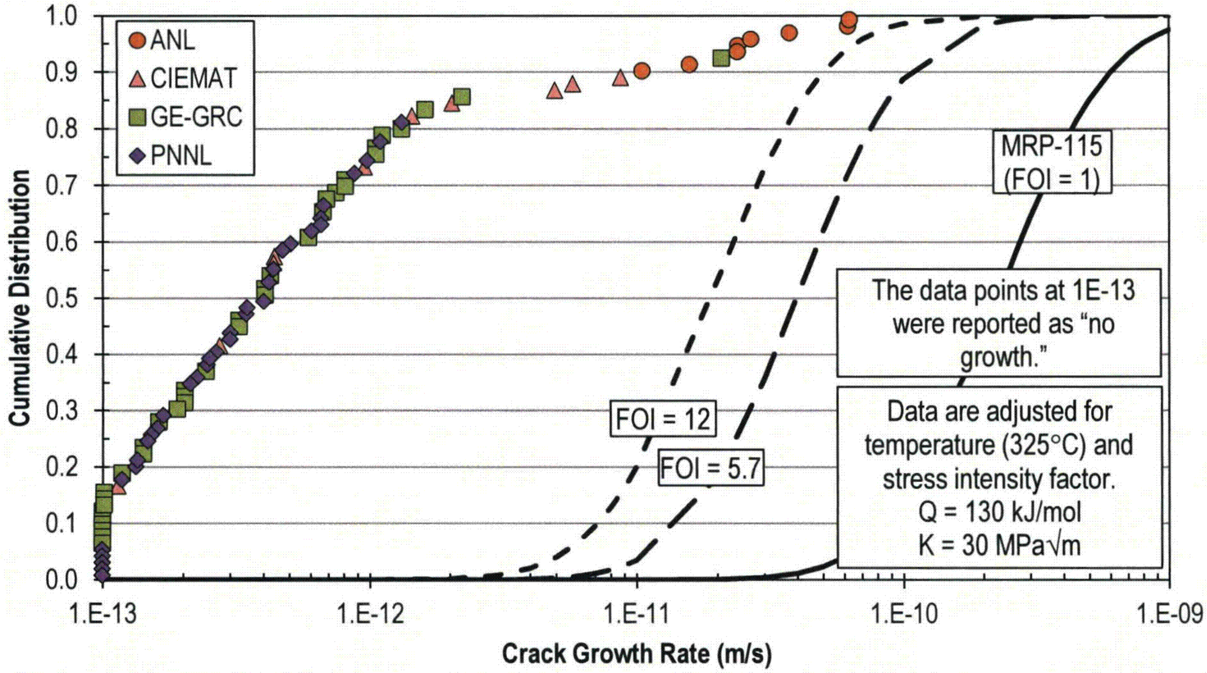

Figure 21. Cumulative Distribution Function of Adjusted da/dt Alloy 52/152 Data from All Laboratories, ≤ 20% Cold Work, Constant Load or K_I

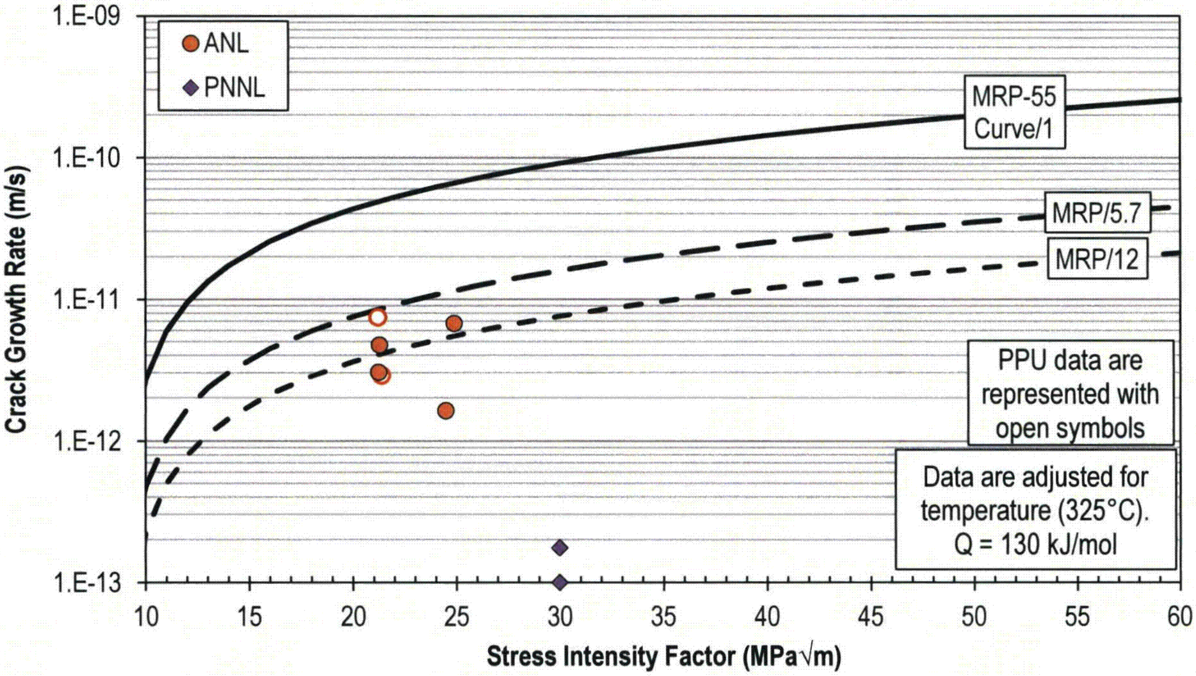

Figure 22. Plot of da/dt versus K_I for Alloy 690 Data from Heat WP142