Stainless Steel SCC Growth Rates

BWRVIP Update Plans

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Background

- BWRVIP stainless steel SCC CGR guidance is used as an input to structural evaluation of flawed reactor internals, most frequently;
  - Core shrouds
  - Core spray piping welds
  - Jet pump riser and diffuser welds
- Correlations used are:
  - Unirradiated SS: BWRVIP-14-A (fluence < $5 \cdot 10^{20}$ n/cm^2)
  - Irradiated SS: BWRVIP-99-A ($5 \cdot 10^{20}$ n/cm^2 ≤ fluence ≤ $3 \cdot 10^{21}$ n/cm^2)
- Guidance has not changed substantially in over 20 years
- There are now many new data that can be considered, including both laboratory data and field inspection data

Updates to BWRVIP-14-A and BWRVIP-99-A Models

BWRVIP-14-A / BWRVIP-99-A Models

- Developed in the early years of the BWRVIP (1998)
- There was an urgent need for such a CGR model to support management of SCC detected in BWR core internals
- Since this model was first developed:
  - There has been a substantial amount of new CGR data generated
  - There have been improvements in testing procedures
  - Guidance has been developed for screening data so that the final datasets used for model development are limited to high quality data
  - There are notable differences compared to more recently developed similar models

BWRVIP-14-A Low Fluence SS SCC CGR Model

- A project to update BWRVIP-14-A is now underway
  - An expert panel panel has been assembled and panel members are now identifying available data along with needed supporting information required for data screening / scoring
  - New database will include substantially more data than used for initial development of BWRVIP-14-A, most notably for the HWC environment
    - 7x - 8x increase in # NWC data
    - 10x – 20x increase in # HWC data
  - Data collection will be complete later in 2024, with expert panel screening / scoring of data to follow
  - New correlations to be developed in 2025

BWRVIP-99-A Irradiated SS SCC CGR Model

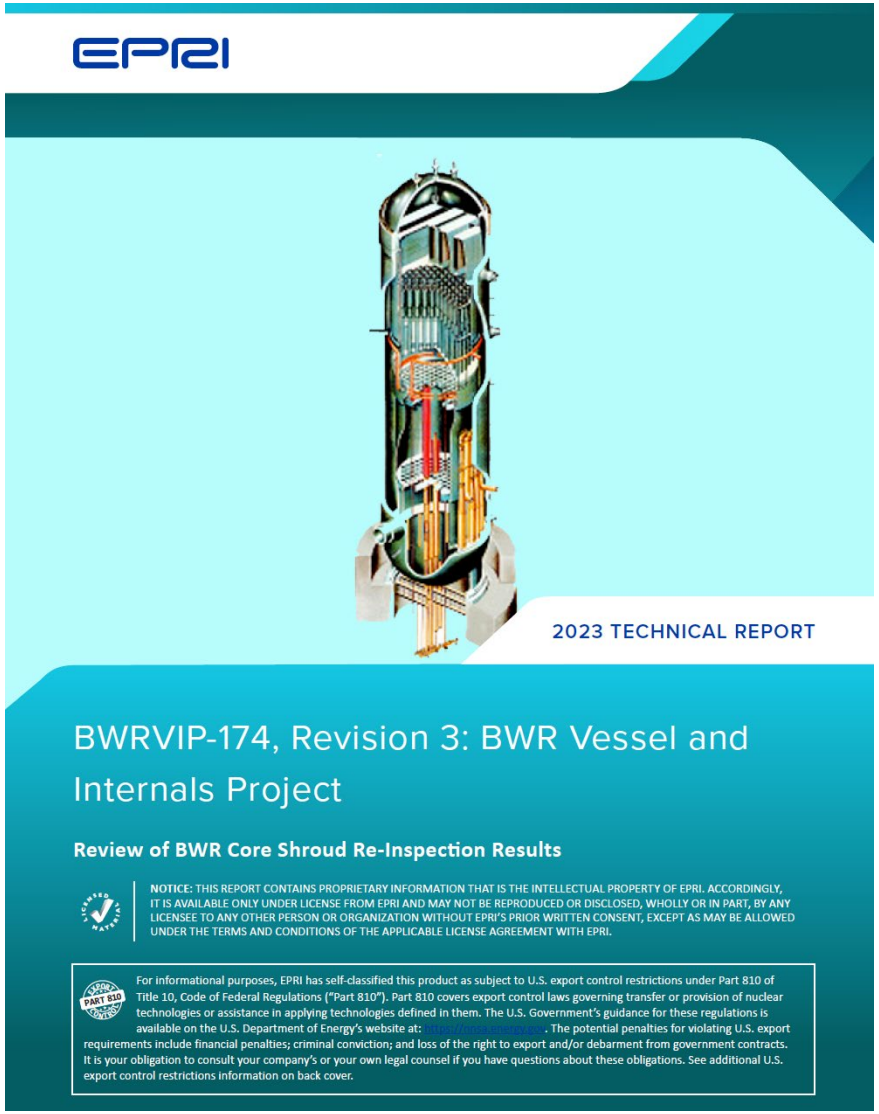
- BWRVIP also has plans to revisit the BWRVIP-99-A model
- Work will follow completion of the update to the BWRVIP-14-A model
- Notably, ASME Code Case N-889 provides an alternative that could be applied in lieu of BWRVIP-99-A
- Initial work will consider the suitability of using CC N-889 as a replacement for BWRVIP-99-A

Field Inspection Data Application to CGRs - Introduction

- EPRI has recently compiled a large amount of NDE data from BWR plants and has performed recent analysis comparing field data to analytical methods
- Results indicate a large disparity in apparent CGRs based on field data and CGRs based on mechanistic predictions
- EPRI is investigating the reasons for these differences and the potential for applying field inspection data to inform CGR correlations

BWRVIP-174, Revision 3 – Core Shroud CGR Evaluation

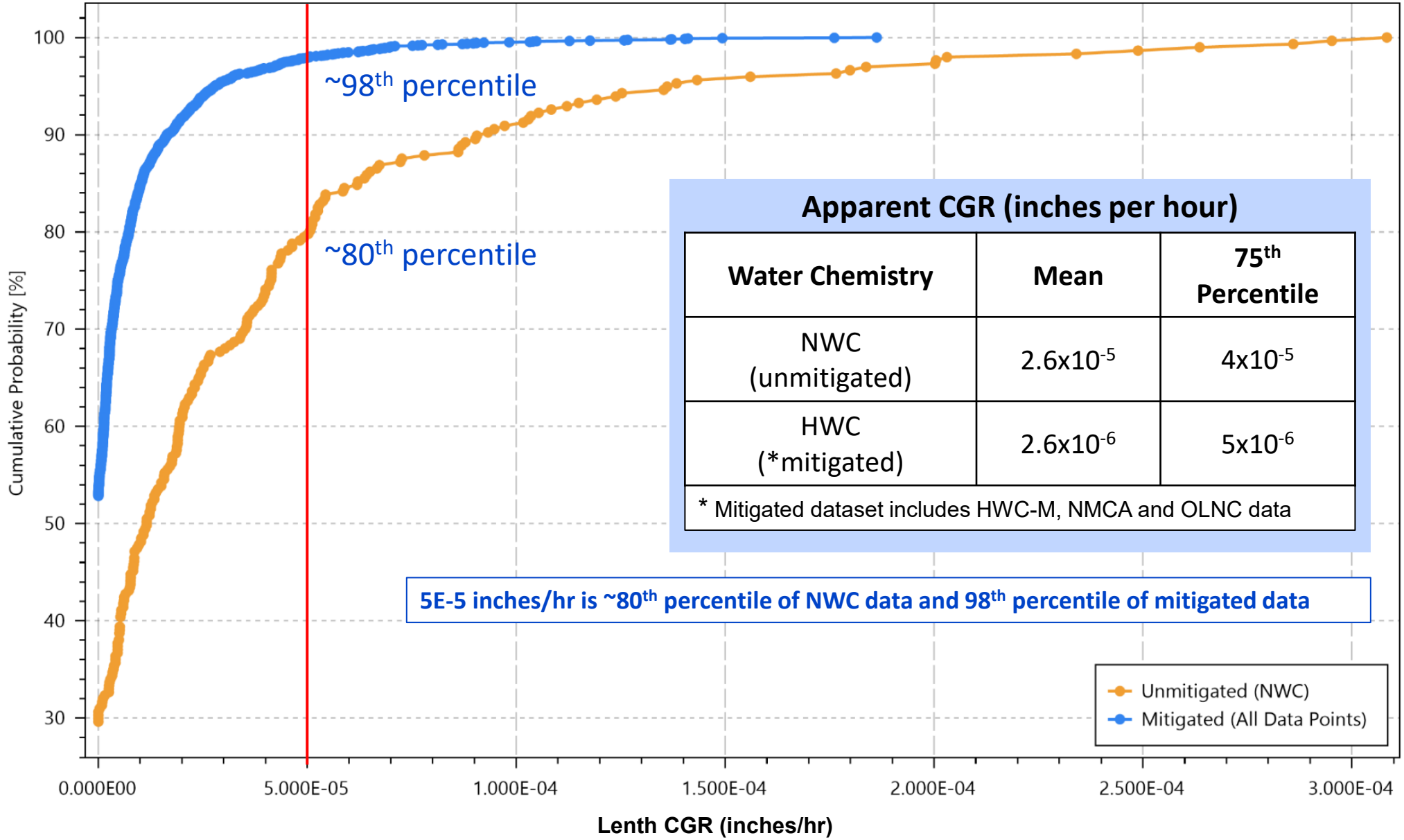
- Published in 2023
- By far, the most detailed evaluation of core shroud inspection data ever performed
  - Data from 33 BWR core shrouds
  - Over 8,000 indication records associated with approximately 5,000 indications
  - Results in over 3,500 CGR estimates for both length and depth directions



Length CGRs – Existing BWRVIP Guidance

- BWRVIP guidance requires use of a length CGR of 5E-5 inches/hr
  - All irradiation levels
  - Both NWC and HWC (no credit for HWC)
  - Has been used as a basis for flaw evaluations and assessment of inspection program requirements since the late 1990s
  - Value was appropriately conservative at the time given uncertainties regarding continued propagation of SCC in BWR reactor internals

Core Shroud Length CGRs – As Estimated from Field Data



Apparent CGR (inches per hour)

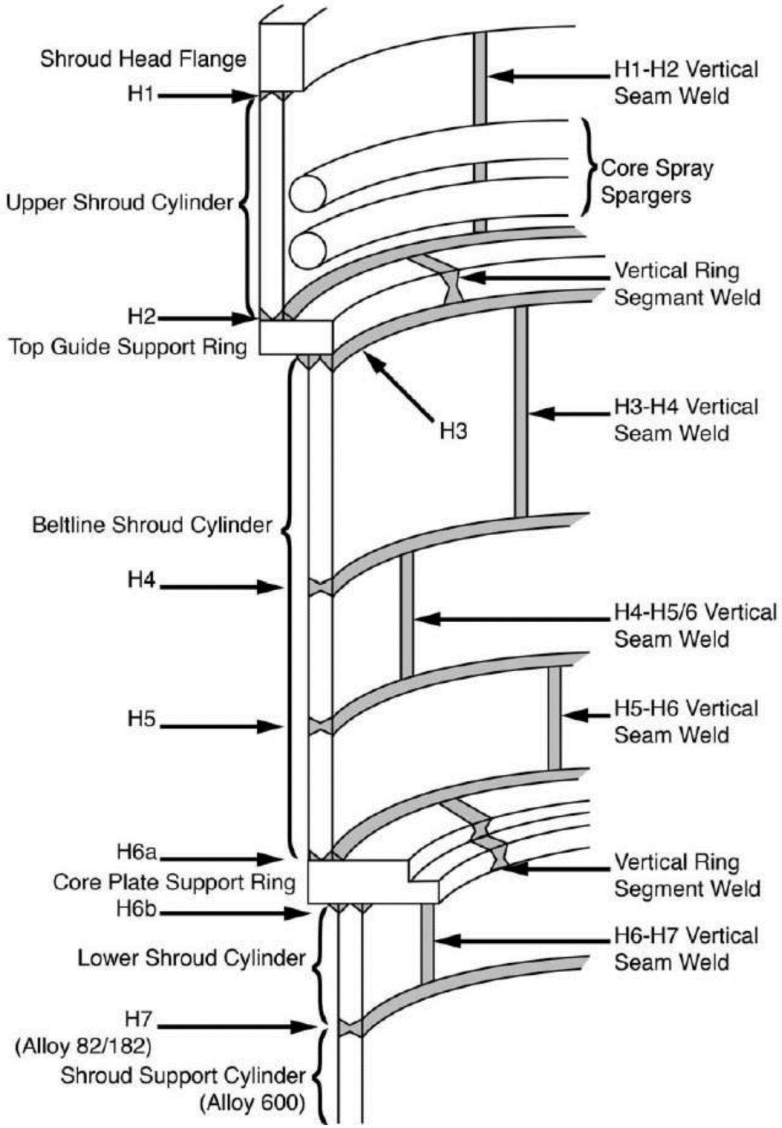
Water Chemistry	Mean	75th Percentile
NWC (unmitigated)	2.6×10^{-5}	4×10^{-5}
HWC (*mitigated)	2.6×10^{-6}	5×10^{-6}

* Mitigated dataset includes HWC-M, NMCA and OLNC data

5E-5 inches/hr is ~80th percentile of NWC data and 98th percentile of mitigated data

Length CGR Comparison Summary

- Assumption of 5E-5 inches/hr for SCC CGRs in stainless steels found to be conservative for both NWC and HWC environments
- If a 75th percentile criterion is applied, a technical basis exists for some reduction in the length CGR for NWC and a strong technical basis exists for use of a lower length CGR for HWC
- All U.S. BWRs have implemented some form of HWC
- Under noble metal catalyzed HWC, all horizontal shroud welds except H1 are mitigated



Comparison to K-Dependent Methods

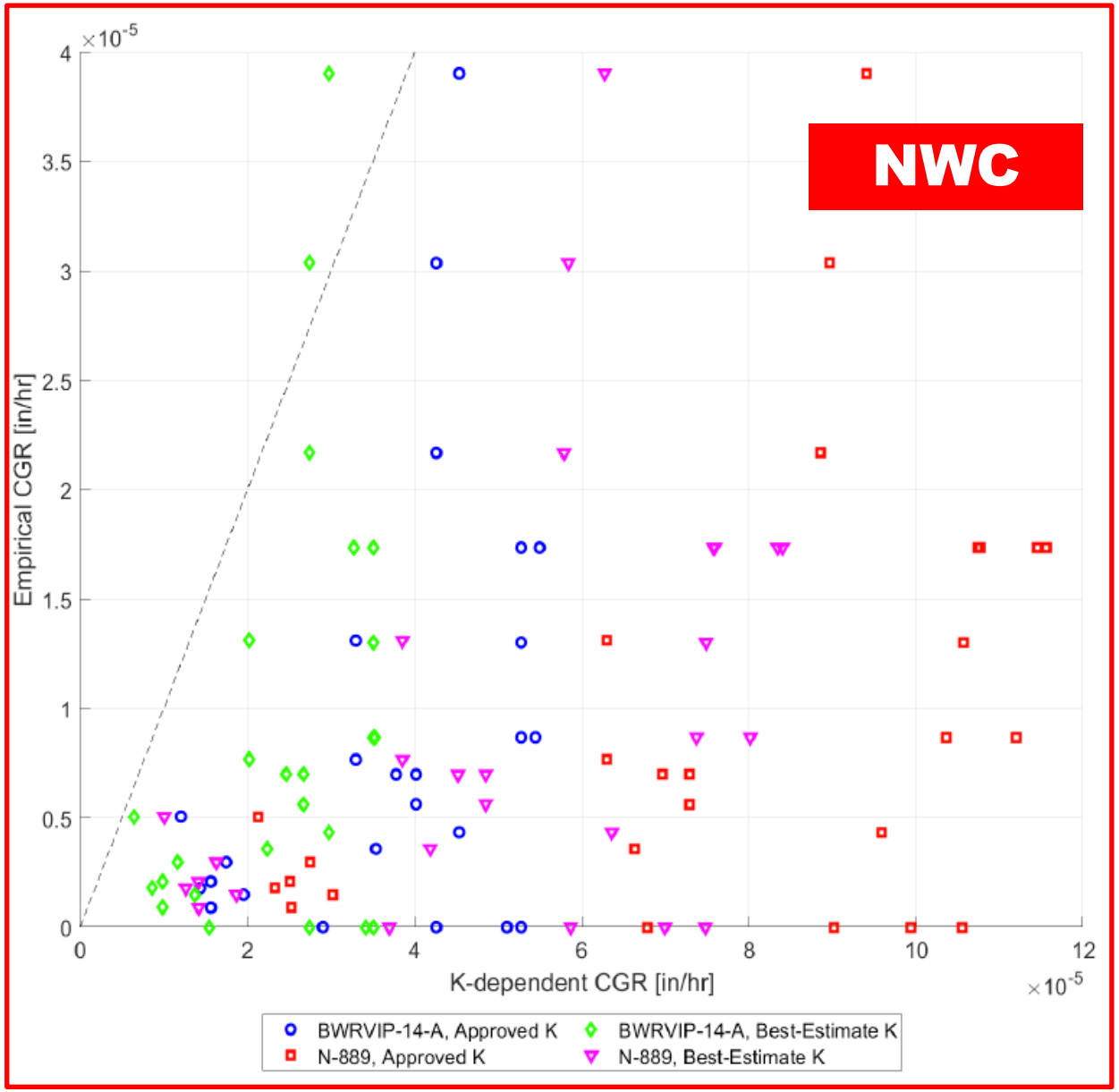
- Estimated depth direction CGRs based on field inspection data were compared to predictions from K-dependent models based on laboratory testing
- Correlations evaluated:
  - BWRVIP-14-A (fluence < $5 \cdot 10^{20}$ n/cm^2)
  - BWRVIP-99-A ($5 \cdot 10^{20}$ n/cm^2 ≤ fluence ≤ $3 \cdot 10^{21}$ n/cm^2)
  - ASME Code Case N-889 (fluence ≤ $3.3 \cdot 10^{22}$ n/cm^2)
- For each model, comparisons were made using two stress distributions
  - Conservative stress intensity factor (SIF) distribution as “approved” for use in BWRVIP-14-A or BWRVIP-99-A
  - More realistic “best estimate” SIF distributions

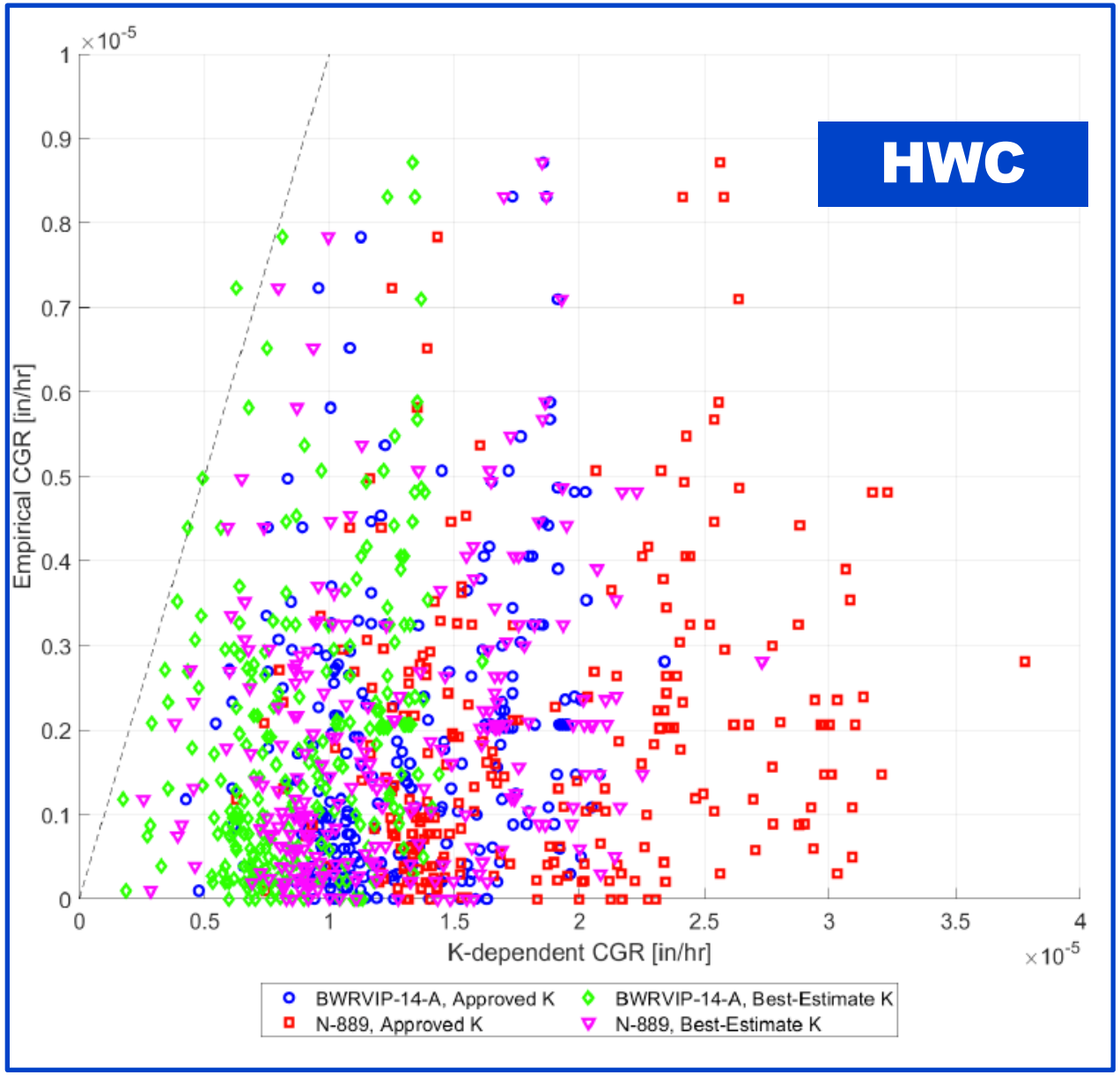
Database of Depth CGRs Available for K-Dependent CGR Comparison

The number of depth crack growth rate data points for each case are:

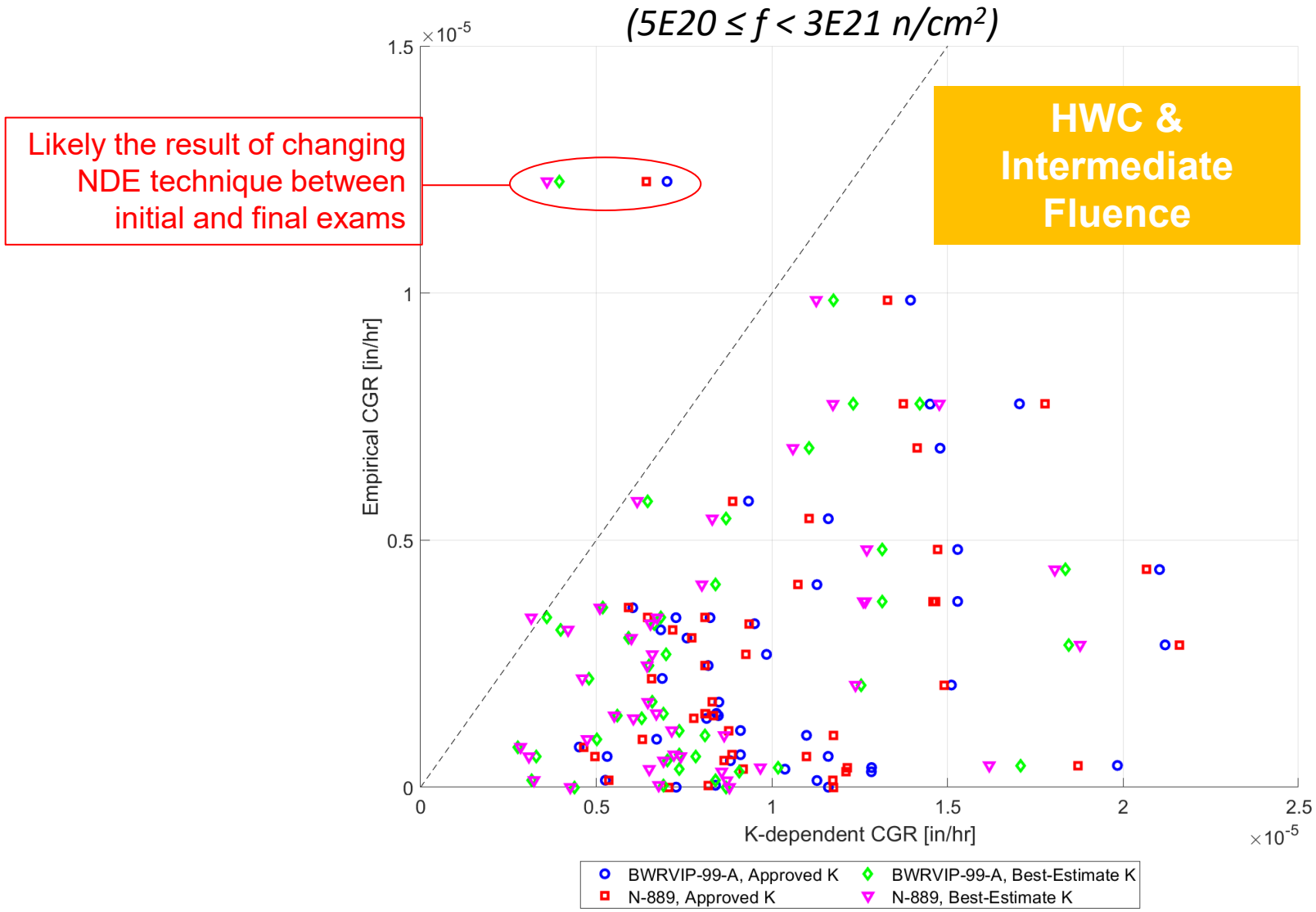
- Low Fluence, NWC: 35
- Low Fluence, HWC: 499
- Intermediate Fluence, HWC: 82
  (5E20 ≤ f < 3E21 n/cm^2 for initial and final depth measurements)

K-Dependent Comparison: Low Fluence (< $5 \cdot 10^{20}$ n/cm^2)





K-Dependent Comparison: HWC at Intermediate Fluence Range



Summary of K-Dependent Methods Comparison

- All mechanistic models appear to be conservative
  - When using “approved” SIF distributions, predicted CGRs are very conservative in comparison with field data
  - When using best estimate SIF distributions, predicted CGRs are closer to CGR estimates based on field data, but remain conservative
- For low fluence, Code Case N-889 is much more conservative than BWRVIP-14-A and Section XI models
- For intermediate fluence, Code Case N-889 and BWRVIP-99-A give similar crack growth rates
- “Best Estimate” results using more realistic residual stress profiles are more accurate and still conservative in almost all cases

EPRI Perspective

- CGRs used in structural evaluations of BWR reactor internals have historically been based on correlations derived from laboratory test results
- It is appropriate to reconsider existing laboratory-based CGR correlations and guidance given the significant amount of new data that have been generated since initial model development and improvements in the methods used to screen and evaluate these data
- However, it is also appropriate to use information from field inspections to inform CGR guidance
  - The BWRVIP is now assessing options for such consideration
  - A reduction in the required length direction CGR of 5E-5 inches/hr for mitigated weld structural evaluations is an initial focus given the strong technical basis provided by evaluation of existing field data

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