U.S. EPR Leak-Before-Break (LBB) Methodology

AREVA NP Inc. and the NRC
June 26, 2008

Introduction

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Agenda

- Meeting Objectives (R. Wells)
- EPR LBB Approach and Methodology (A. Nana)
- Summary (A. Nana)
- Combined License Information (COL) Items and ITAAC (R. Wells)
- Surge Line Stratification (T. Bhagwagar)

Meeting Objectives

- Provide an overview of the LBB approach on three piping systems for U.S. EPR
- Provide clarifications and responses to initial comments/questions
  - Identify key internal references for audit review
- Respond to questions regarding NRC confirmatory LBB analysis

U.S. EPR LBB Approach

Ashok Nana
Lead Engineer for LBB Analyses

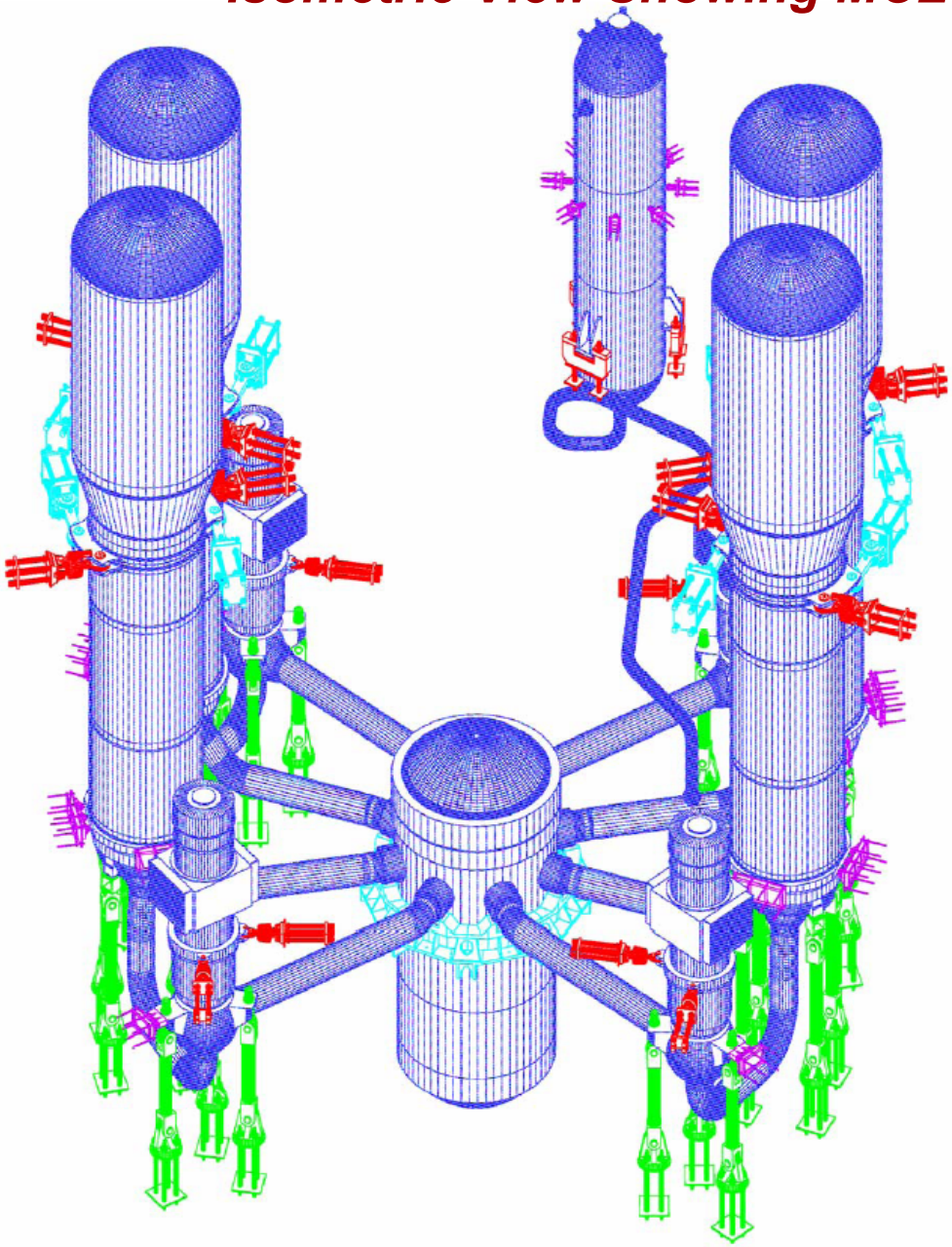
Overview

> Three high-energy piping systems are identified for LBB

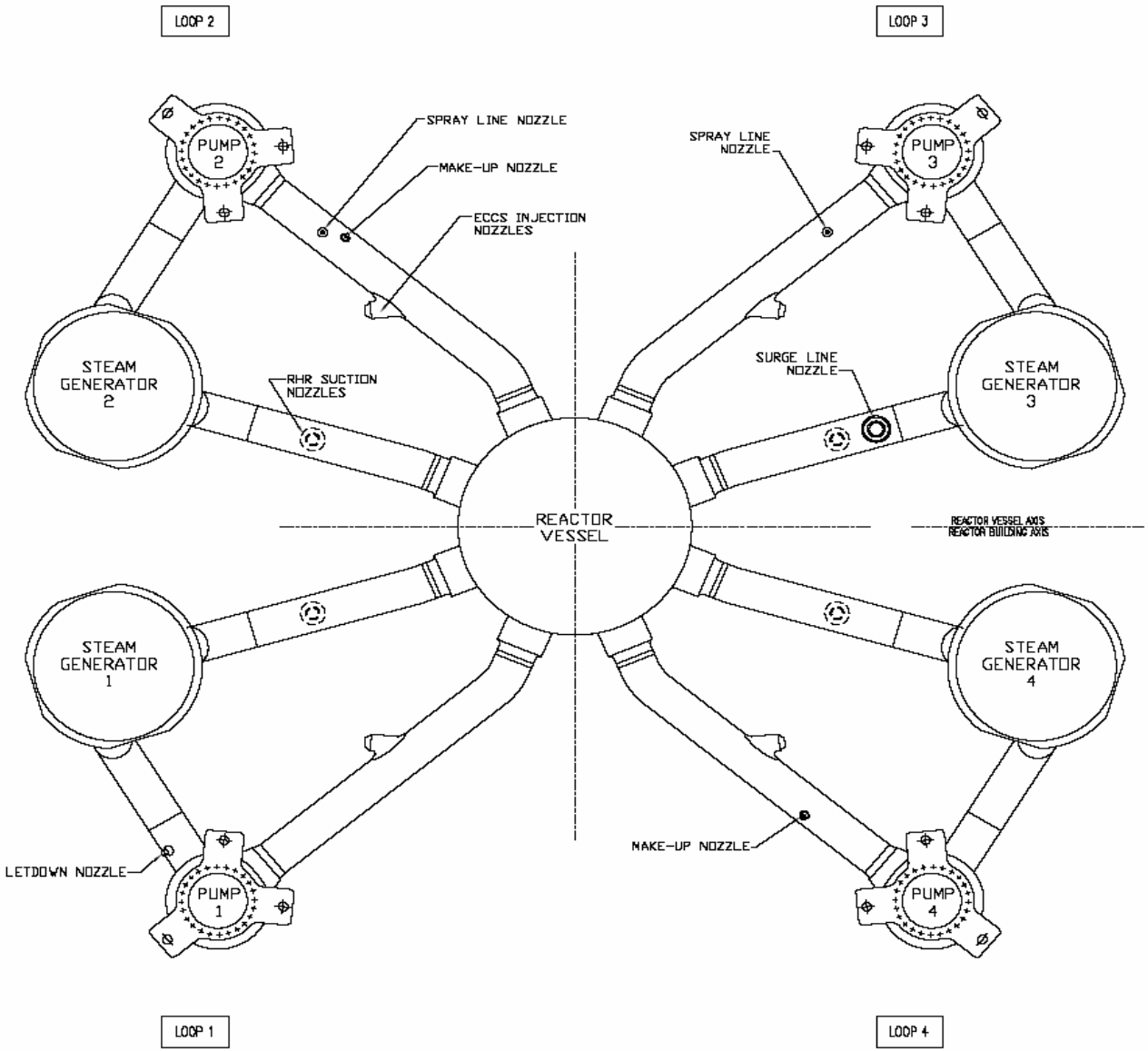
- Main coolant loop (MCL) piping
  - Hot leg, cold leg and crossover leg
- Pressurizer surge line (SL), and
- Main steam line (MSL) piping inside containment
  - From steam generators to first anchor point location at Containment Building penetration

3 LBB Piping Systems

Isometric View Showing MCL and SL Piping

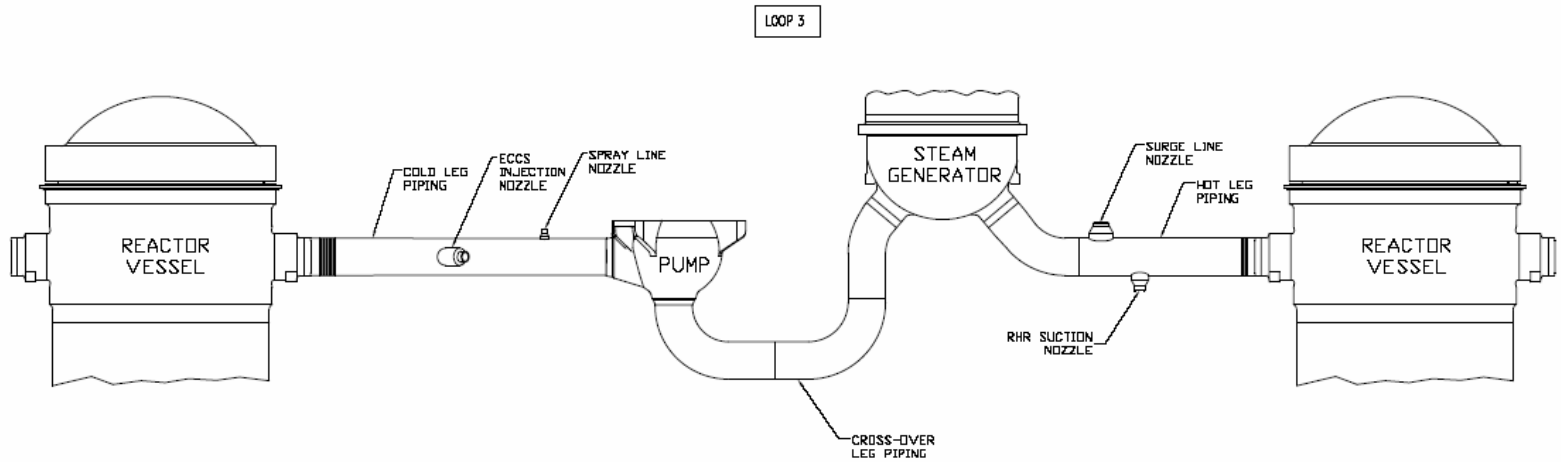


Plan View of MCL Piping



See FSAR Tier 2 Fig. 3.6.3-1

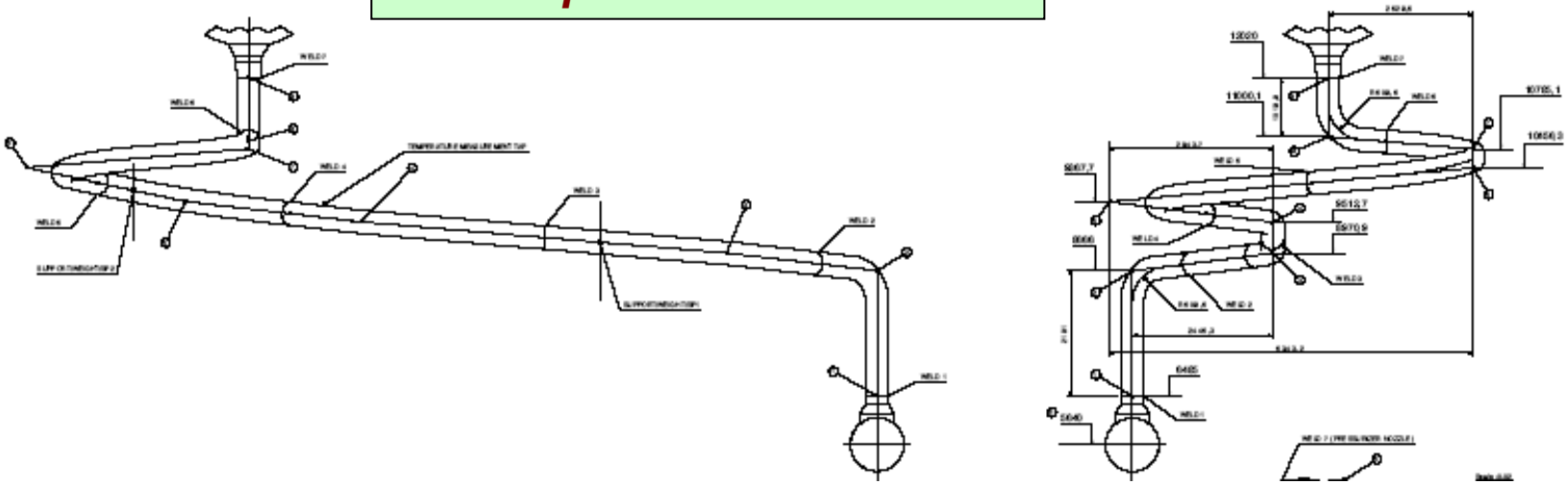
Elevation View of MCL Piping



See FSAR Tier 2 Fig. 3.6.3-2

Layout of SL Piping

Note: PZR Nozzle DM Weld will be revised to indicate it is a shop weld



See FSAR Tier 2 Fig. 3.6.3-3

Layout of MSL Piping

Inside Containment Portion to 30JMK10BQ110

LBB Applicability

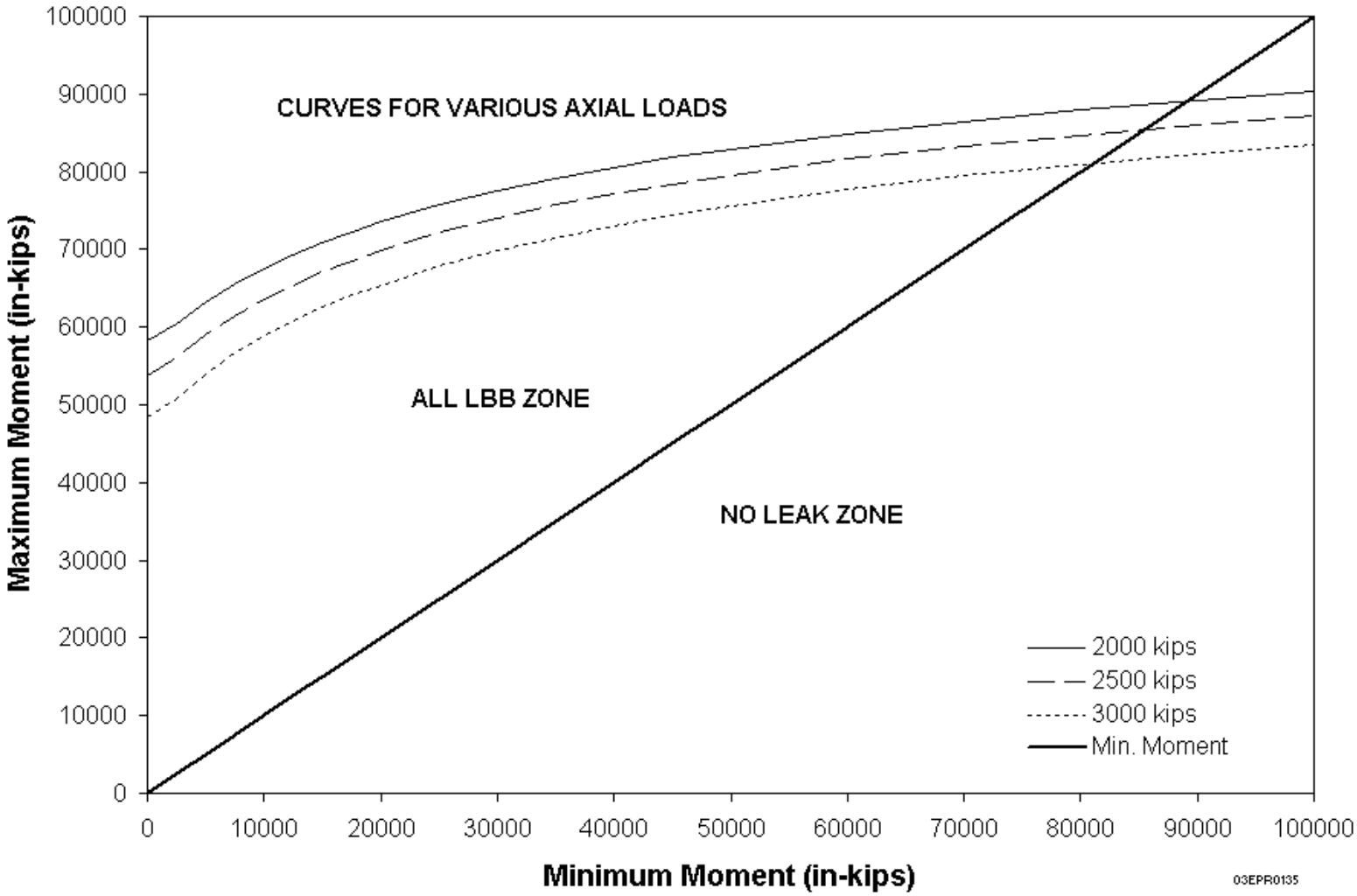
- Application of LBB limited to piping – "*not-susceptible*" to failure from various degradation mechanisms in service
  - Demonstrate – probability of fluid system rupture is "extremely low"
  - Demonstrate/address following issues are not a concern:
    - Pipe rupture due to water hammer
    - Creep damage
    - Degradation by erosion, erosion/corrosion, due to unfavorable flow conditions and chemistry
    - Corrosion resistance of piping
    - Fatigue cracking or failure of piping system
    - Thermal aging and thermal stratification
    - Potential indirect sources of pipe rupture
    - Piping material not-susceptible to brittle cleavage type failure
    - Failure prevention and detection
  - LBB - applied to Class 1 & 2 or equivalent piping systems

Addressed in FSAR Tier 2 Section 3.6.3.3

Overall LBB Methodology

- *Typical LBB analysis considers applied loadings in piping system – these are known, such as for operating plants*
- *The LBB analysis performed for U.S. EPR is consistent with methods and criteria of NUREG 1061, Vol. 3 and SRP 3.6.3*
- *In this approach the final LBB results are in the form of "Allowable Load Limit" (ALL) diagrams*
  - *If applied loading points lie within the ALL window, LBB is justified – with appropriate LBB safety margins already considered in window*

Typical ALL Diagram Considering Various Axial Loads



Overall LBB Methodology

- Like typical LBB analysis, it involves:
  - Phase I: performing leak rate analysis – to obtain leakage crack sizes (ℓ) with recommended margin of 10 on leak detection capability
  - Phase II: performing detailed flaw stability analysis –
    - Considering safety margin of two on leakage crack size or (2ℓ)
- Like typical LBB analysis, for consideration of selection of location for LBB, it involves:
  - Pipe or nozzle geometry
  - Base and weld metal materials
  - Operating pressures and temperatures

Overall LBB Methodology

- In typical LBB analysis - actual loads are known:
  - Only those locations that have least favorable combination of stress and material properties needs to be demonstrated for LBB
- In the ALL diagram approach:
  - A significant number of initially assumed normal operating loadings are considered in the leak rate analysis
  - Corresponding maximum allowable moment loads are then determined through flaw stability analysis

Identification of LBB Location

> **Considering geometry, materials and operating conditions.**
  - **If any of the three parameters change it is identified as an LBB location**
  - **Example - Following this process of selection, five locations are determined for the MCL piping:**
    - **1) RV outlet nozzle region at hot leg**
    - **2) SG inlet nozzle at hot leg**
    - **3) SG outlet nozzle**
    - **4) Crossover leg, RCP outlet nozzle, cold leg, RV inlet**
    - **5) RCP inlet nozzle region**

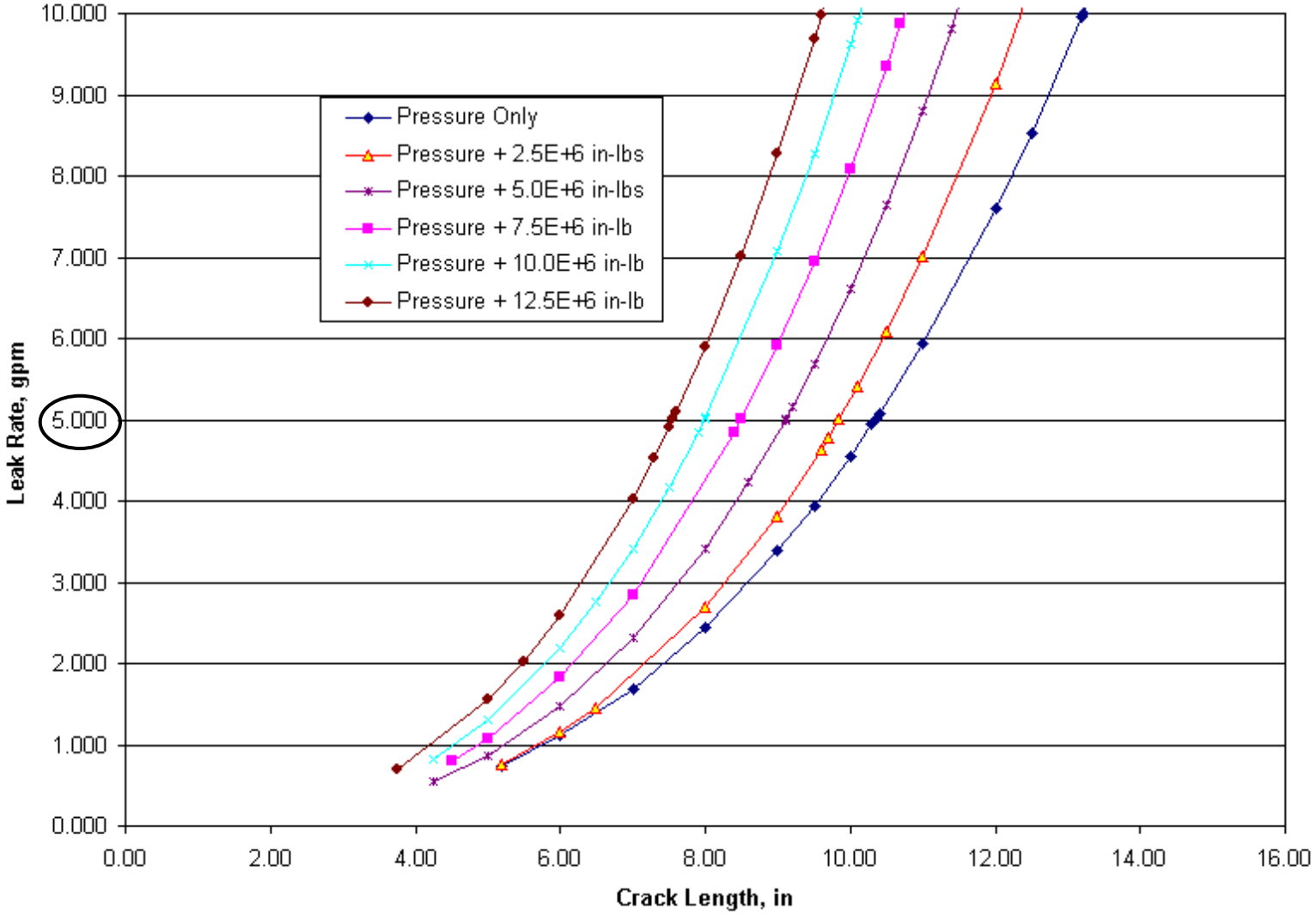
Phase I - Leak Rate Analysis

- **Perform leak rate analyses**
  - **For MCL & SL piping – In-house code KRAKFLO used**
    - **Benchmarked for subcooled & saturated liquid conditions**
  - **For MSL piping – SQUIRT code used**
    - **Benchmarked for saturated steam conditions**
  - **Various assumed normal operating loads are considered.**
    - **Moment loadings ranging from a small fraction of the yield strength to gradual increments of loadings above yield strength of the material**
    - **Axial load due to pressure**
    - **Low external pipe axial load conservatively assumed**
  - **Leakage flaw sizes are then determined considering a factor of 10 times the leak detection capability flaw size**
  - **Fatigue flaws postulated at all locations.**
  - **Lower bounding limit curve or minimum moment curve is generated**

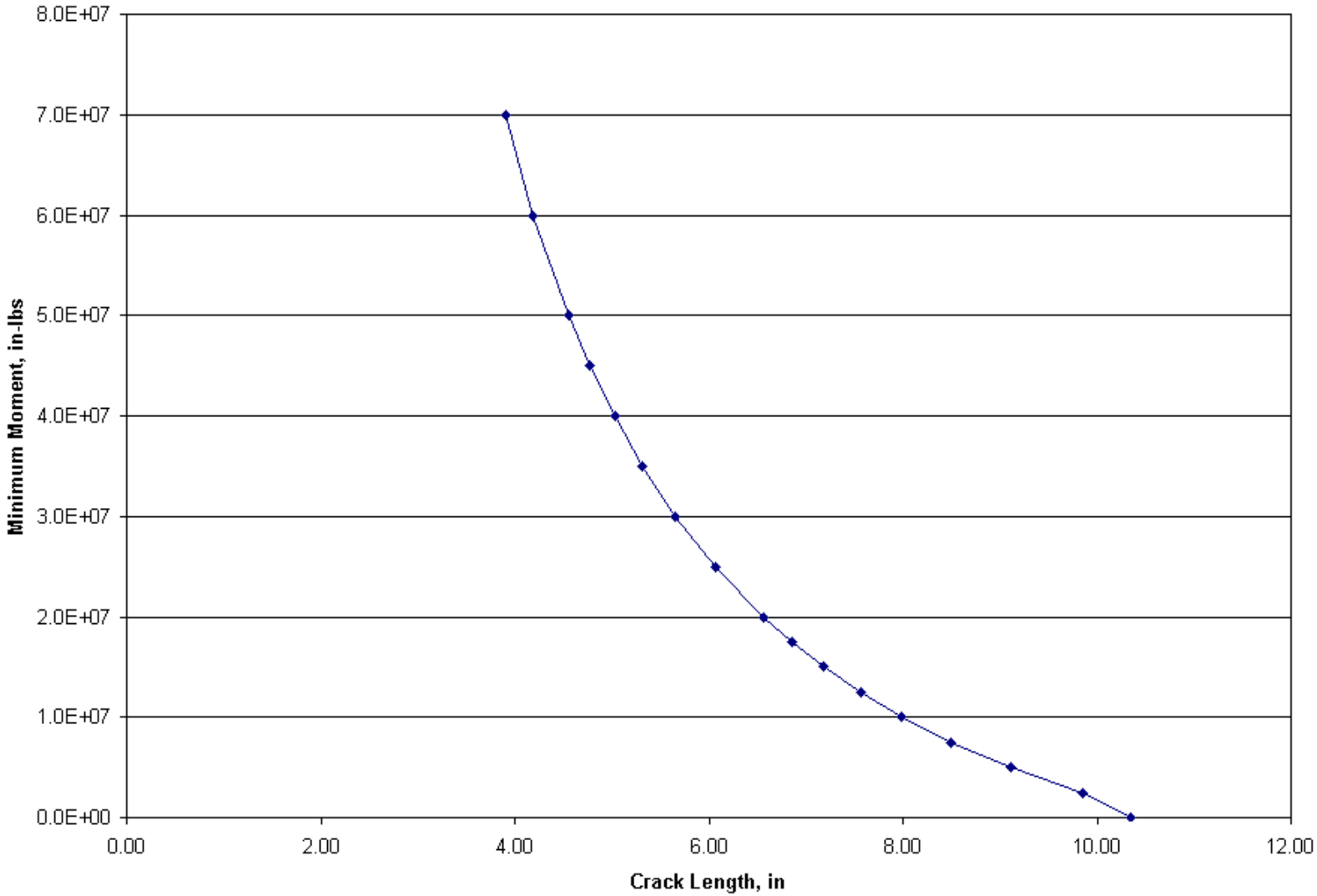
Leak Rate Analyses

- For the MCL Piping:
  - Loadings ranged from pressure only case to small increments in loadings of 2.5E6 in-lbs up to 20E6 in-lbs.
  - From 20E6 in-lbs to 50E6 in-lbs; increment increased to 5E6 in-lbs
  - From 50E6 in-lbs to 140E6 in-lbs; increment increased to 10E6 in-lbs
- A family of curves of:
  - Leak rate versus crack lengths are thereby established for each loading condition
    - Leak rates ranging from 1 to 10 gpm are shown for a typical location
- For MCL, with leak detection capability of 0.5 gpm
  - Therefore, desired leakage crack sizes are for 5 gpm

Leak Rate Versus Crack Length – SG Inlet Nozzle



Minimum Moment Vs Crack Length Curve



For 5 gpm Leak Rate

Minimum Moment Curve

> **The leak rate analyses help establish the Minimum Moment Curve**
  - **Minimum moment corresponds to deadweight, steady state pressure and thermal expansion moment for normal operation.**

Lower Bound Limit Curve

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Materials & Material Properties

- The MCL and SL are fabricated from F304LN stainless steel (SS) and 308/308L SS welds
  - Safe ends F316LN
  - Dissimilar metal welds (DMW) – Alloy 52/52M
  - All welds fabricated using GTAW process
  - Attached RV nozzles – SA-508 Grade 3 Class 1
  - Attached SG & PZR nozzles – SA-508 Grade 3 Class 2
- RCP casings – SA 351 CF3
- MSL piping – SA 106 Grade C carbon steel matl.

EPR

Materials & Material Properties

- Material Testing Program:
- Material properties of comparable materials
  - Obtained from industry literature
- For MSL – used experimental data

J-R Curve for 2.75T CT Specimens

J-R Curve for 1.5T CT Specimens

J-R Curve for Alloy 52 Fusion Line

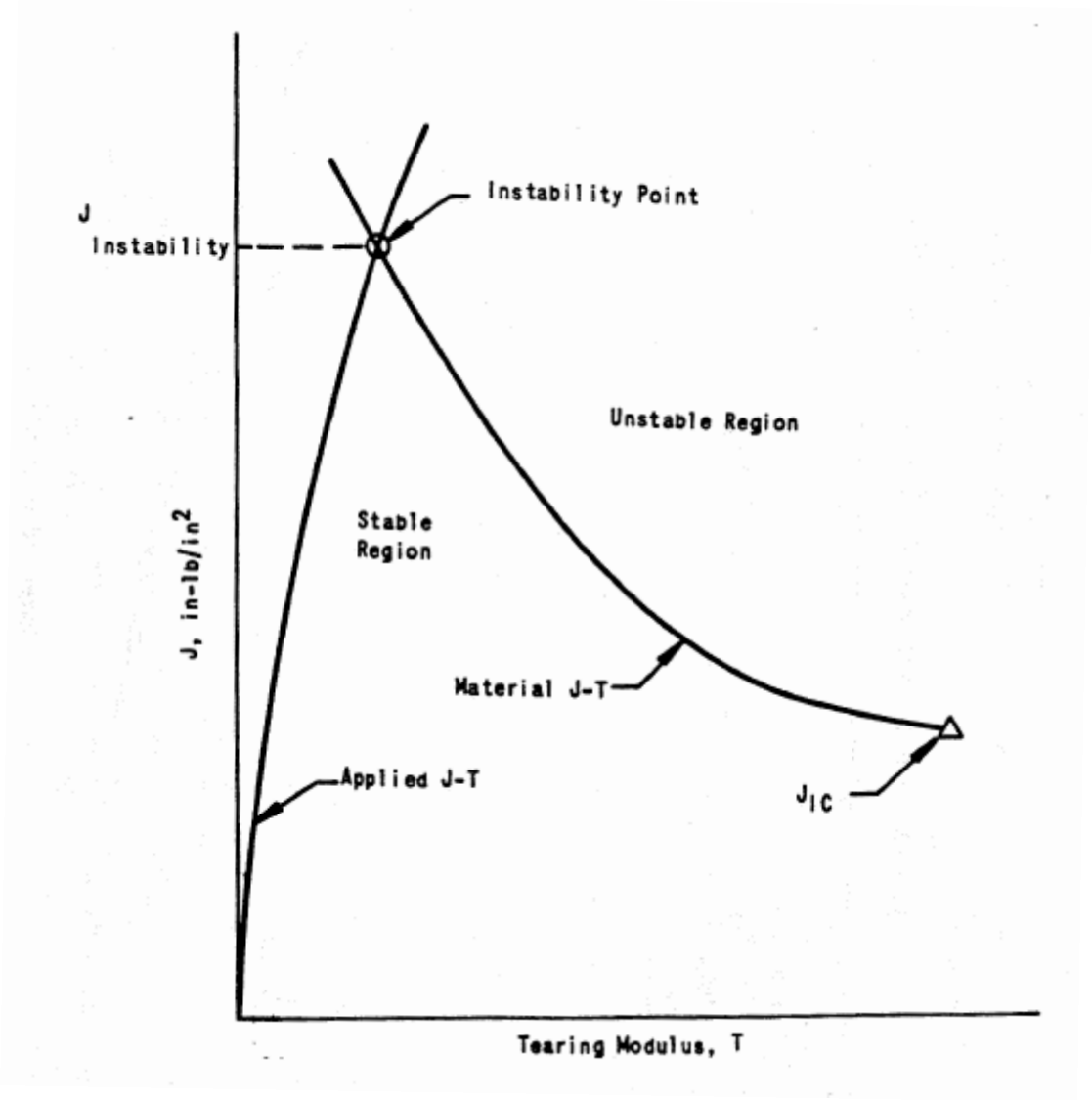
J-R Curve for RCP, Nozzles & Alloy 52

J-R Curve for SA 106 Grade C - MSL

Phase II – Flaw Stability Analysis

- ***Perform flaw stability analyses – Applied J***
- ***Circ. T-W crack in straight pipe solution***
  - ***For MCL & MSL piping – Used EPRI/GE method for axial tension & bending solution***
  - ***For SL piping – Used EPRI/GE method for bending solution***
    - ***Effect of axial load also considered through determining Meq***
- ***Detailed J-Tearing analysis is performed***
  - ***Since a margin of two is recommended between leakage crack size, ℓ, and critical crack size, 2ℓ***
    - ***Leakage crack sizes from Phase I are doubled for flaw stability analysis i.e. flaw size, a = ℓ***
  - **For normal operating + SSE loadings – since absolute sum load combination is considered, a factor of 1.0 on loadings is applicable**

Illustration of Instability Point in J/T Analysis



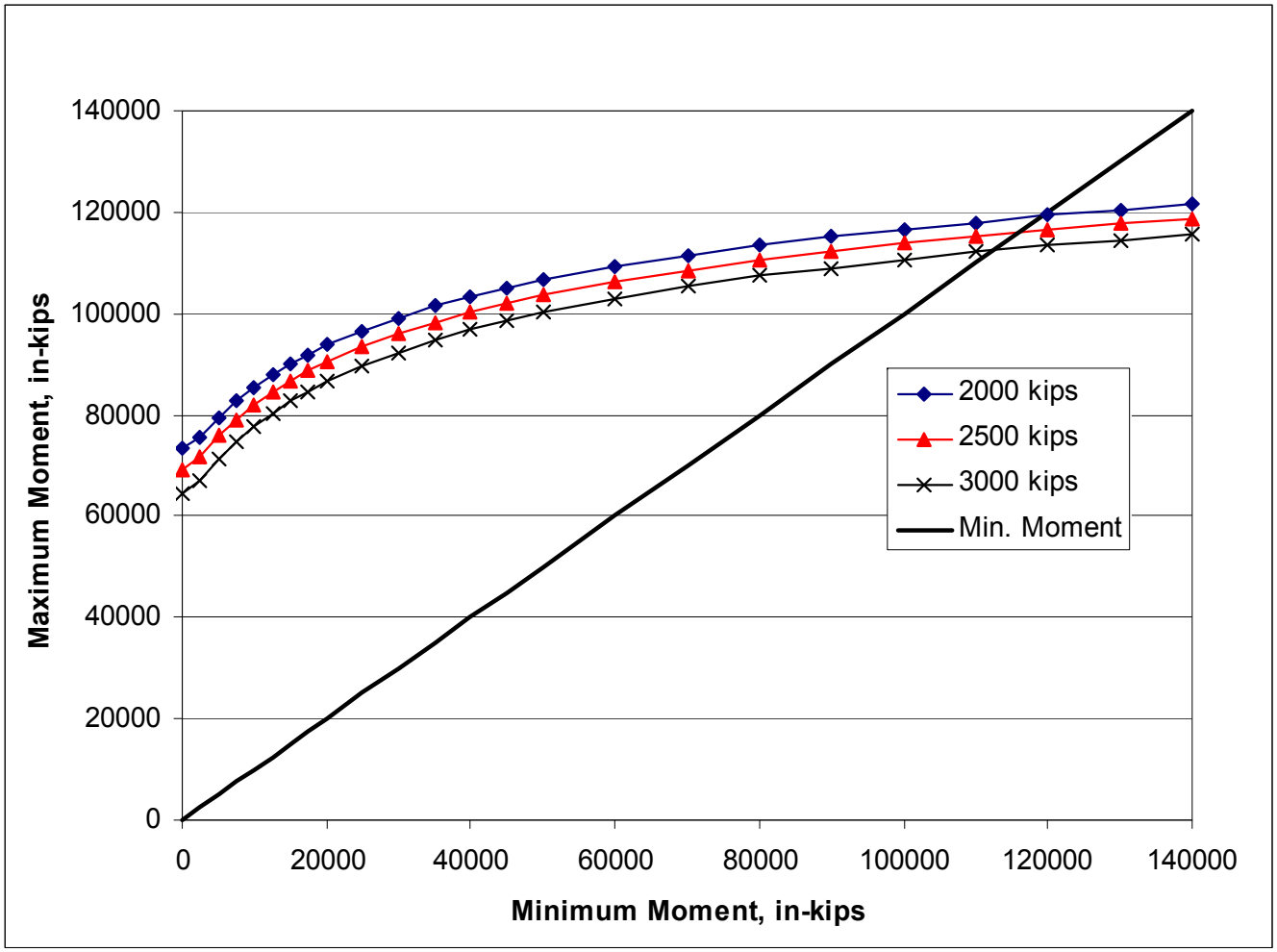
Phase II – Flaw Stability Analysis

- At each applied minimum moment load, maximum allowable moment load considering a factor of two on leakage crack size is determined.
- Joining these loci of points creates the Upper Bounding Limit Curve called the ALL diagram for a given LBB location

Phase II – Flaw Stability Analysis

- **From Phase I - leak rate analysis**
  - **Lower Bound or Minimum Moment Curve is determined**
- **From Phase II –J-T analysis method**
  - **Upper Bound or Maximum Moment Curve is established**
- **Combining the results from the above analyses results in an ALL diagram**

ALL Diagram for SG Inlet Nozzle – Various Axial Loads



ALL Diagram – Showing Allowable LBB Zone

LBB Demonstrated

- *For each major segment of piping system*
  - *Locations identified for LBB*
    - *Geometry, materials, and operating condition*
  - *Unique ALL diagram*
  - *Actual loads when available – compared against the associated ALL diagram*
  - *If all the loads fall in the ALL LBB zone – LBB is demonstrated*

Preliminary Loads - SG Inlet Nozzle

Preliminary Loads – MSL (SF=2)

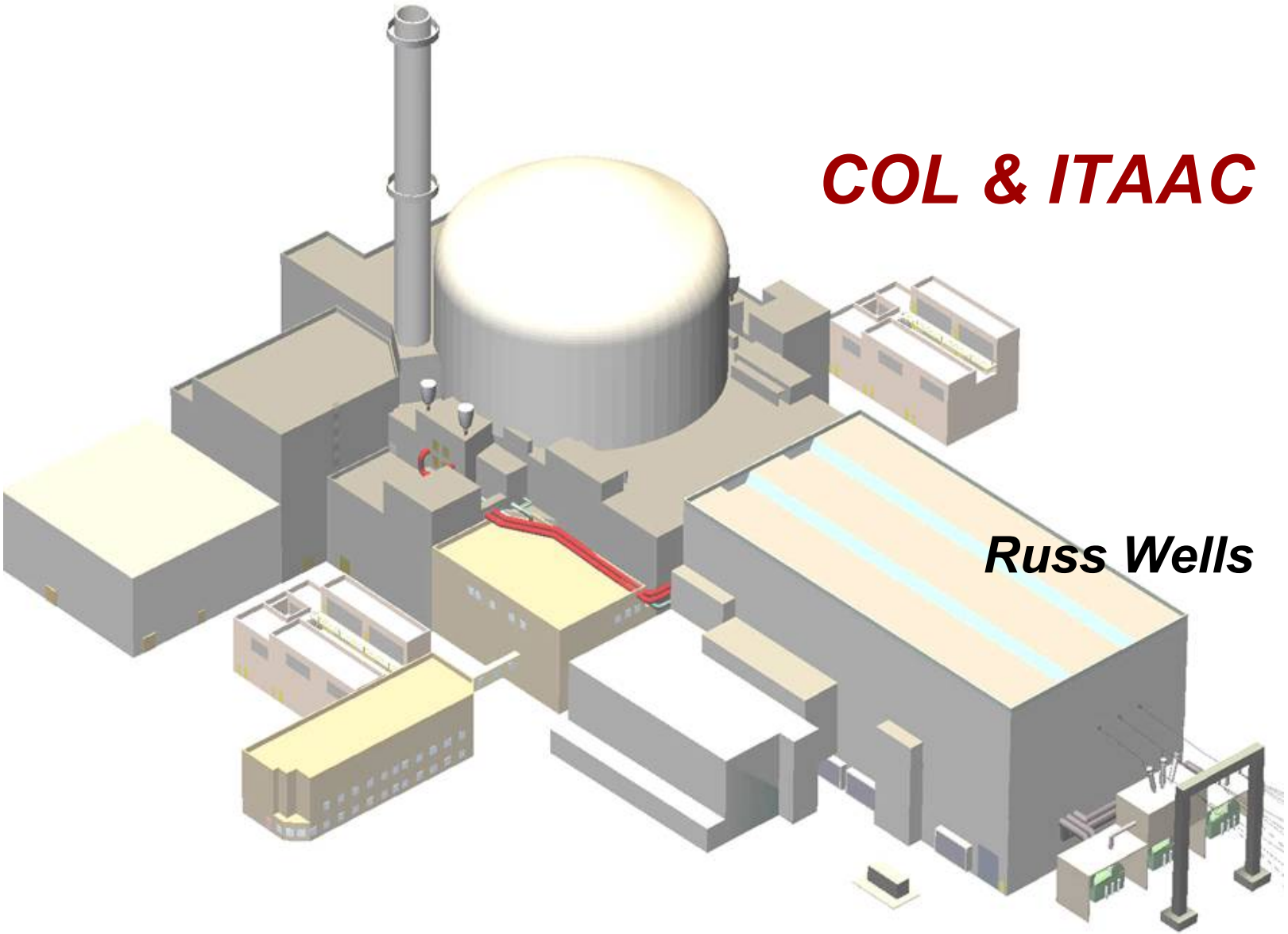
Preliminary Loads – MSL (SF=1.7)

Preliminary Loads – SL (SF=2.0)

Summary

- ***LBB analysis conforms to GDC 4 and applicable regulatory guidance***
- ***LBB can be successfully demonstrated for the entire piping system***
- ***Benefit of this approach – LBB analysis would not need to be re-performed due to future structural loads re-analysis.***
- ***ALL diagram concept – very convenient*** **for structural analysts to verify that LBB requirements continues to be met for the given piping system**

COL & ITAAC



Russ Wells

Regulatory Implementation of LBB Approach

- **As noted in previous slides, the U.S. EPR LBB approach is intended to be a "bounding approach" for purposes of the design certification application (FSAR Tier 2 Section 3.6.3)**

- **Verification of this bounding approach is accomplished through COL information items and ITAAC**

LBB COL Information Items

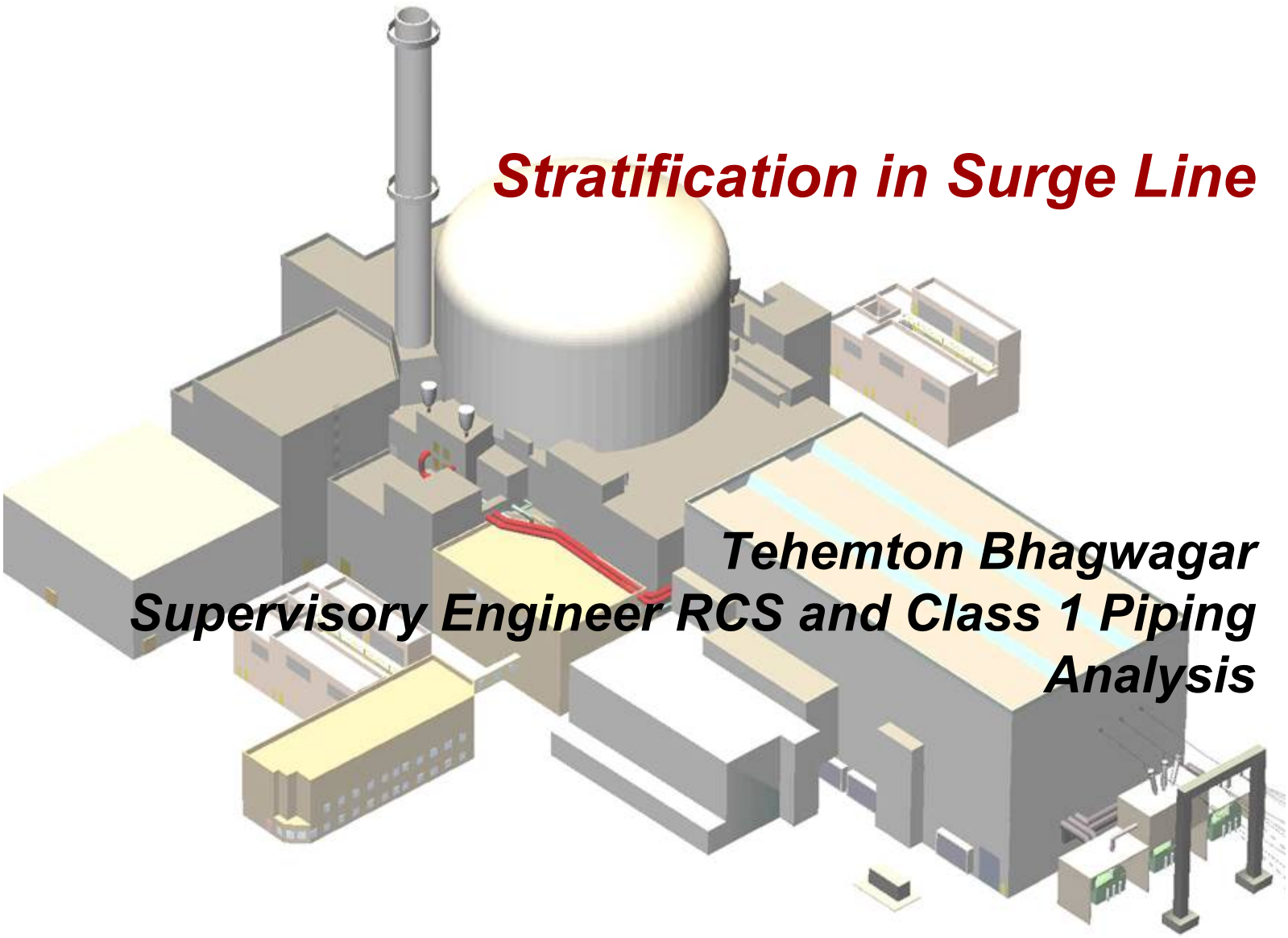
- **COL Information Item 3.6-3 (FSAR Tier 2 Section 3.6.3)**
  - **A COL applicant that references the U.S. EPR design certification will confirm that the design LBB analysis remains bounding for each piping system and provide a summary of the results of the actual as-built plant specific LBB analysis, including material properties of piping and welds, stress analyses, leakage detection capability, and degradation mechanisms.**

ITAAC

> **FSAR Tier 1 Table 2.2.1-5—RCS Inspections, Tests, Analyses, and Acceptance Criteria**

Design Commitment	Inspection, Test or Analysis	Acceptance Criteria
The piping and interconnected component nozzles listed in Table 2.2.1-1 have been evaluated for LBB	An analysis will be performed.	An analysis exists that assesses the LBB capability of the piping and equipment listed in Table 2.2.1-1

Stratification in Surge Line



Tehemton Bhagwagar
Supervisory Engineer RCS and Class 1 Piping Analysis

Surge Line Stratification

> **Low potential for thermal stratification in U.S. EPR surge line due to:**

- **Improved geometry**
  - Continuous 5 degree slope from the PZR to the HL to prevent water stagnation
  - Vertical take-off from the HL with a 6.7D length to minimize turbulent penetration
- **Improved system operation**
  - Continuous spray bypass flow at normal operation to suppress turbulent penetration
  - The PZR-to-HL temperature difference is minimized during plant heat-up by initiating in-surges via the CVCS system

Surge Line Stratification in Operating Plants

SL Stratification Results for a Westinghouse PWR

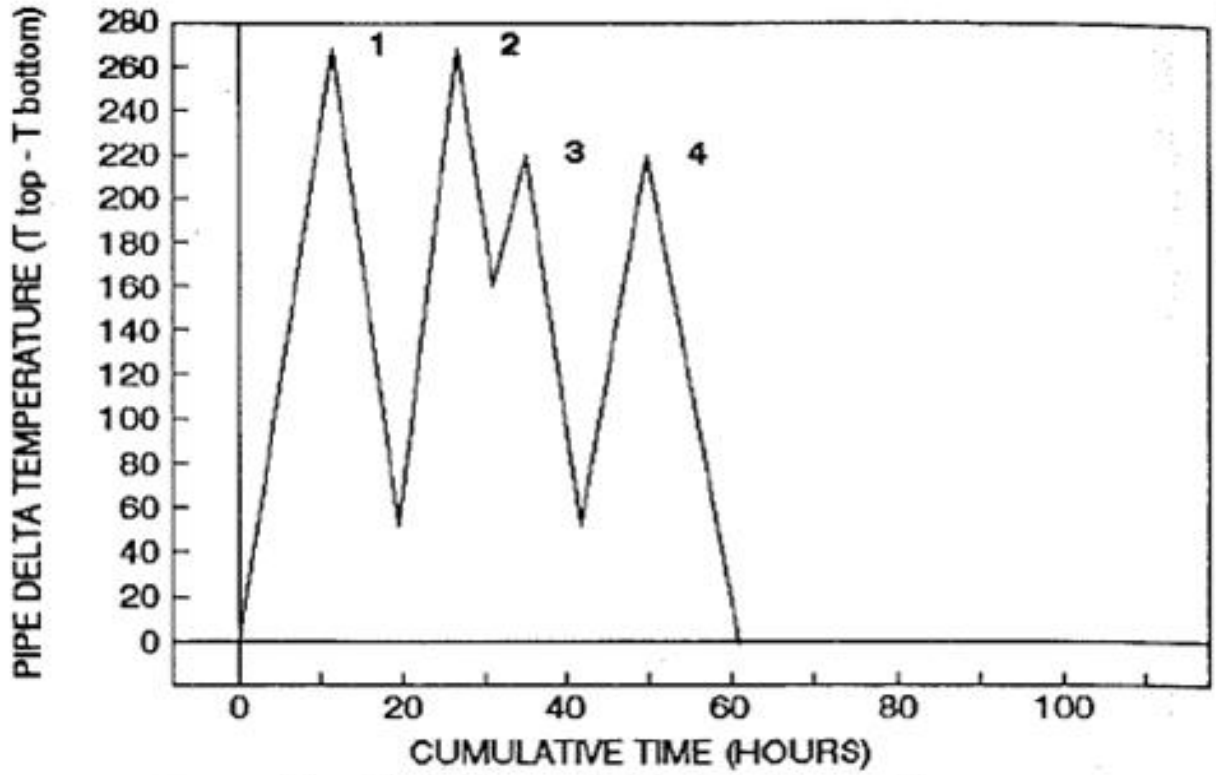


Fig. 10(*a*) Thermal stratification cycles

Source: "An Investigation of Thermal Stress Ranges Under Stratification Loadings," T.H. Liu and E.L. Cranford, Westinghouse Electric Corporation, published in Journal of Pressure Vessel Technology, Transactions of the ASME, Vol. 113, May 1991, page 330

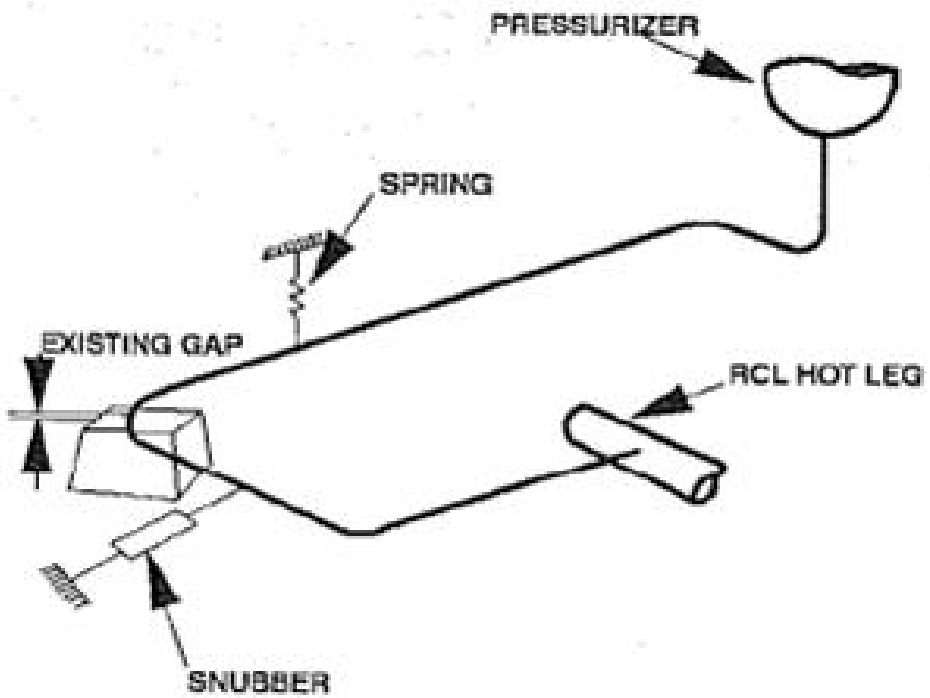


Fig. 1 Surge line piping system layout

Surge Line Geometry for a Westinghouse PWR

Source: "An Investigation of Thermal Stress Ranges Under Stratification Loadings," T.H. Liu and E.L. Cranford, Westinghouse Electric Corporation, published in Journal of Pressure Vessel Technology, Transactions of the ASME, Vol. 113, May 1991, page 326

SL Stratification Results for a B&W PWR

Surge Line Geometry for a B&W PWR

SL Stratification Results for a French PWR

Surge Line Geometry for a French PWR

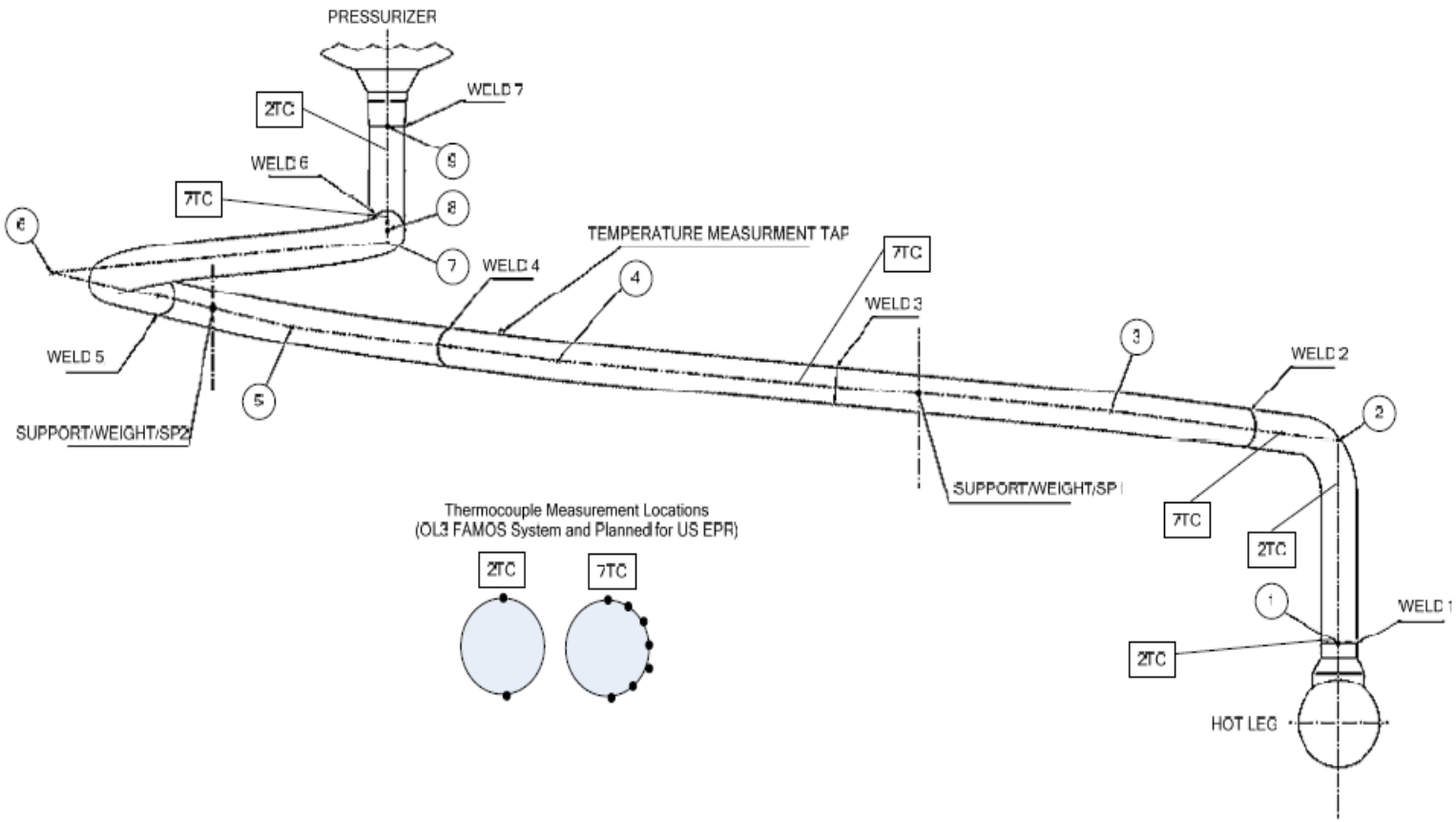


Figure 4-1: US EPR Surge Line

Surge Line Geometry for U.S. EPR

Questions?