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Development of Evaluation Models for TH Safety Analysis

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This presentation contains only personal observations and opinions of the presenter and should not be interpreted as an official regulatory position of the USNRC.

RTR License Renewal Challenges

The original safety analysis was performed a long time ago and there might be limited institutional knowledge of how it was performed. The SAR does not contain everything.

- The people and the calculations tools used to perform the original safety analysis are no longer available.
- The evaluation model methodology used for the analysis were sometimes based on flawed or incomplete understanding.
- RTRs do not always have dedicated staff to perform safety analysis
- New people might need to reconstruct the design basis with new calculation tools for the license renewal safety analysis

Evaluation Model Concept

An evaluation model (EM) is the calculational framework for evaluating the behavior of the reactor system during a postulated transient or design-basis accident.

- Includes one or more computer programs, special models, and all other information needed to apply the calculational framework to a specific event and includes
  - Procedures for treating the input and output information (particularly the code input arising from the plant geometry and the assumed plant state at transient initiation)
  - Specification of those portions of the analysis not included in the computer programs for which alternative approaches are used
  - All other information necessary to specify the calculational procedure.
- The entire evaluation model must be considered during the development, assessment, and review process.

NRC Regulatory Guide 1.203, "Transient and Accident Analysis Methods", is a good source of information about developing Evaluation Models

Developing Evaluation Models

- TH analysis codes like TRACE, RELAP5, or PLTEMP are not evaluation models.
- They are general purpose reactor system safety analysis computer codes that can be used as part of an evaluation model.
- Complex computer codes with many input options can produce unreliable and incorrect results if used without modelling guidelines and assessment.
- Developing an evaluation model including modelling guidelines and assessment for a validated evaluation model can be a lot of work but it is important to do this to obtain reliable results for safety calculations. It is also important in understanding the limitations of the evaluation model.

Developing Evaluation Models

- Determine requirements for the evaluation model
  - Specify Analysis Purpose and Reactor Design
  - Specify Figures of Merit
  - Identify Systems, Components, Phases, Geometries, Fields, and Processes That Must Be Modeled
  - Identify and Rank Key Phenomena and Processes (PIRT)
- Develop an assessment base consistent with the determined requirements (separate effects and integral effects tests)
- Develop the evaluation model
- Assess the adequacy of the evaluation model
  - It is desirable to quantify the magnitude of the uncertainty in the results compared to the safety margin.
- Develop comprehensive, accurate, and up-to-date documentation
- Follow an appropriate quality assurance protocol

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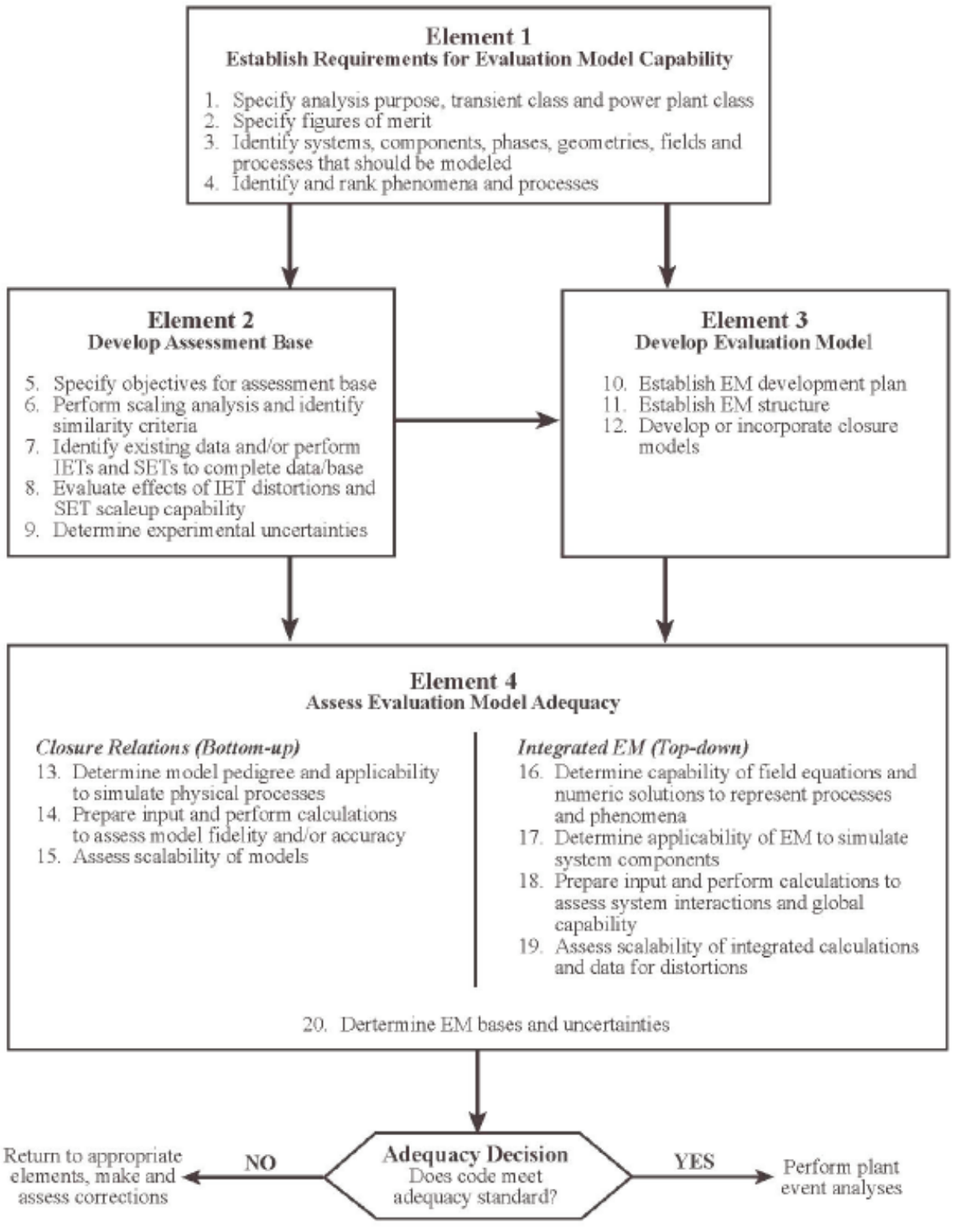
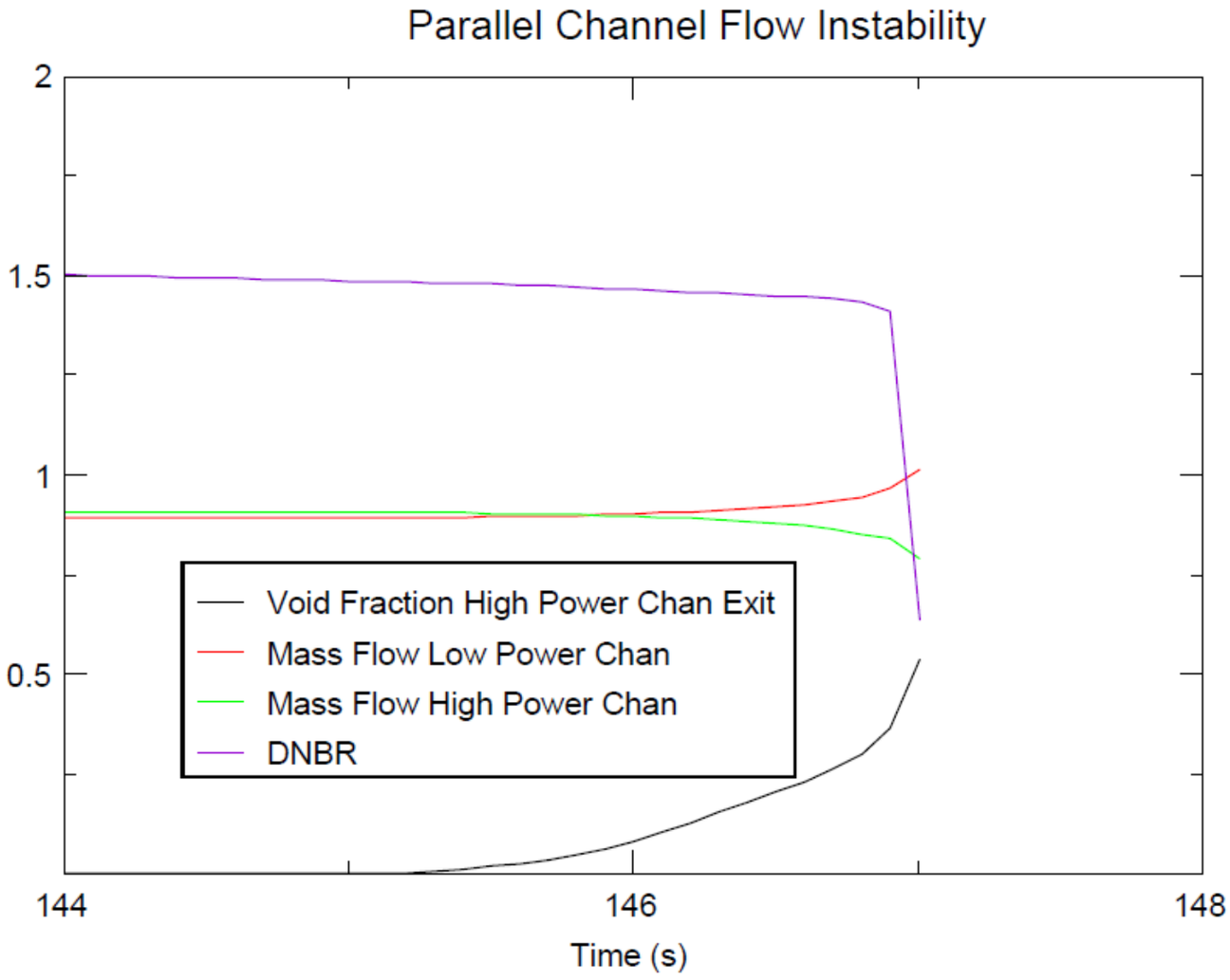
Developing Evaluation Models



Determine Requirements

Example: Plate Fuel Reactor Parallel Channel Flow Instability

- Plate fuel reactors have many parallel channels driven by a constant pressure drop condition set by plenum pressures.
- The onset of vapor generation in hot channel increases pressure drop and reduces flow in hot channel. The hot channel becomes flow starved and can hit CHF limits.



Historical Methods for Calculating Thermal Limits in Plate Fuel Reactors

Custom fit to existing CHF correlation (Croft 1964)

- The burnout value correlated with multipliers on the Bernath correlation. The multipliers had large variation with channel geometry and flow conditions.
- Burnout occurs at power corresponding to 85 to 92% of power needed to reach saturated exit conditions.

Empirical method based on fluid conditions and subcooling margin at channel exit (Waters 1966)

- Recognized mechanism causing CHF was due to subcooled boiling and increased pressure drop.
- Recognized importance of lateral power variation and lack of lateral mixing.

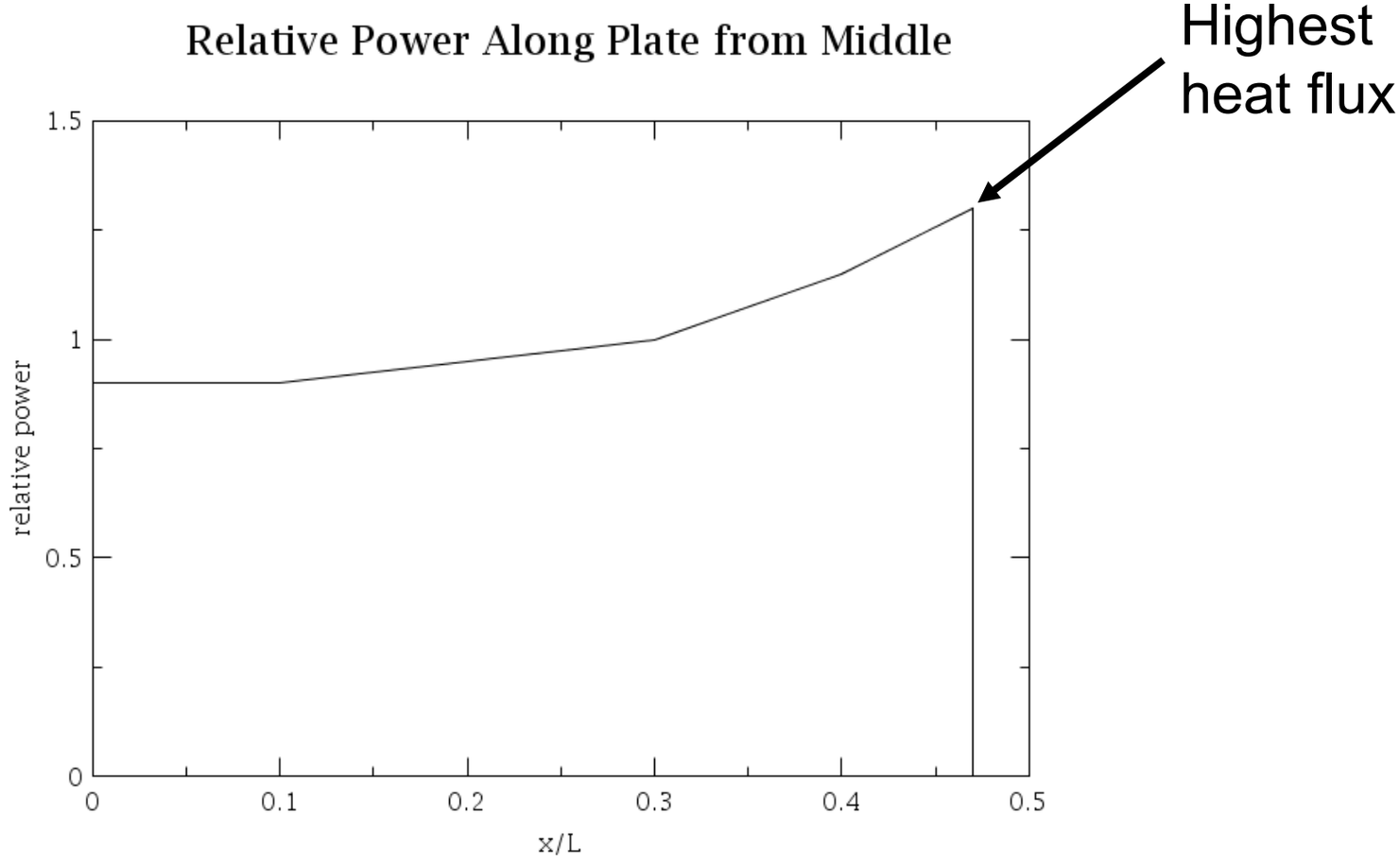
Pressure Drop versus Flow curve (S-curve) minimums correlated as a function of the ratio of heated length to heated diameter. The S-curve give flow stability limits. (Whittle and Forgan 1967)

- The W&F method depends on integrated effects of axial power shape, flow conditions, and L/D
- Vapor generation and increased pressure drop in the channel depends on onset of subcooled boiling
- Subcooled boiling vapor generation depends on local heat flux and fluid conditions
- Reactors with the same integrated axial power can have different heat flux shapes

How should stability calculations be performed?

Experience with plate fuel reactor stability calculations (Feldman 2011)

- Stability calculations are sensitive to criteria used and the way calculations are performed.
- Results can be non-conservative if lateral power shape variation and lack of lateral mixing is not adequately accounted for.



How can the Evaluation Model be assessed and validated?

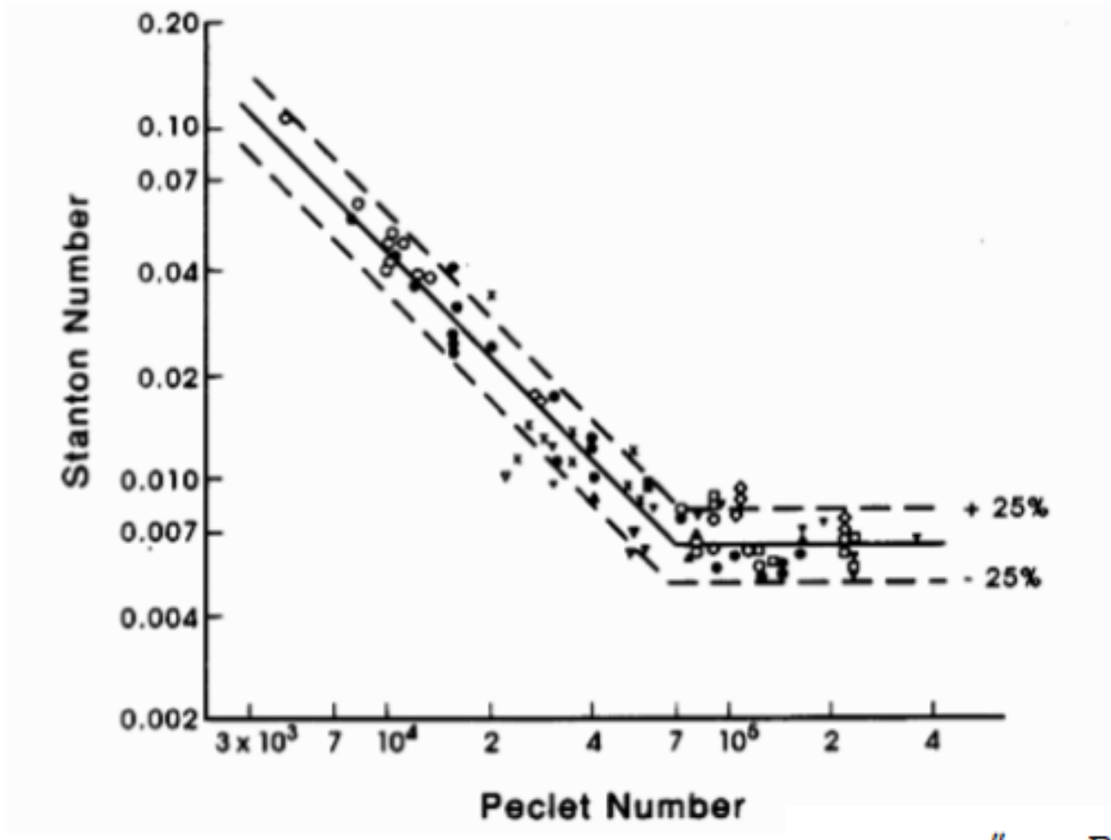
- Develop a methodology to calculate the stability margin using chosen criteria.
- Choose assessment data to validate chosen criteria and important models and correlations that affect the calculation of the chosen criteria.
- Determine the accuracy and uncertainty of the method compared to the assessment data.
- Determine the sensitivity and uncertainty of the results due to uncertainties in important correlations.
- Compare the uncertainty of the results to the safety margin in the calculations.
- Try to estimate and understand the uncertainty from know limitations and things missing in the model.

Example: Use of Subcooled Boiling in Stability Calculations

Subcooled Boiling Correlation (Saha and Zuber 1974)

Determines the onset of significant voids.

- Pe ≤ 70,000 is thermally controlled region
- Pe > 70,000 is the hydrodynamically controlled region



$$Nu = \frac{q''_{NB} \cdot D_h}{k_l \cdot (T_{sat} - T_l)}$$

$$Nu = 455 \quad : \quad Pe \leq 70000$$

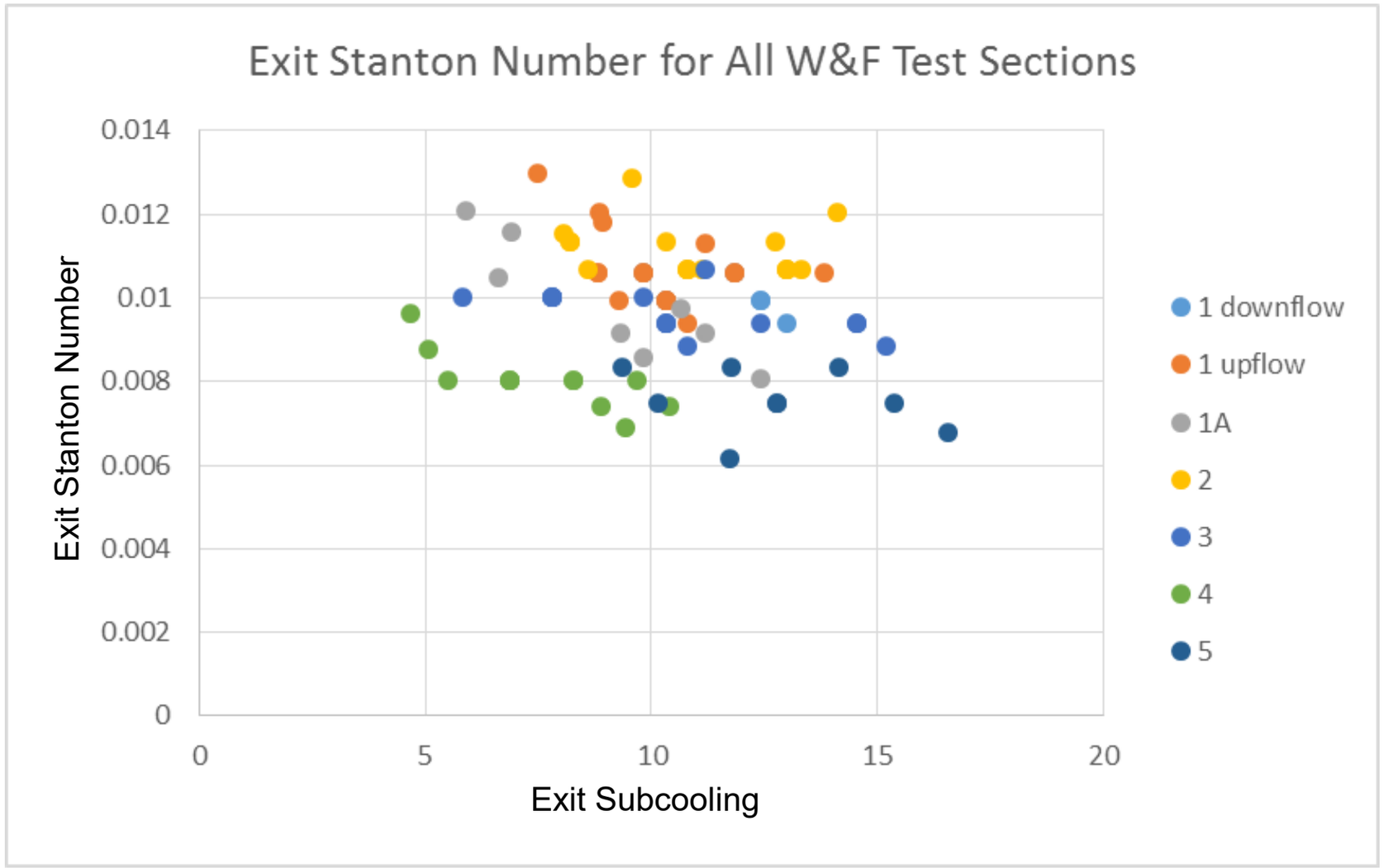
$$St = 0.0065 \quad : \quad Pe > 70000$$

$$St = \frac{q''_{NB}}{G \cdot c_{p,l} \cdot (T_{sat} - T_l)}$$

$$Pe = \frac{Nu}{St}$$

W&F Data Exit Stanton Number

Effect of Test Section on Exit Stanton Number at Onset of Instability for W&F Data



Documentation

Document the Evaluation Model for Now and for the Future. It should be complete enough so that a new knowledgeable analyst can pick it up and use it when needed.

- The documentation that comes with the computer codes is only part of the needed documentation. You also need documentation to show that the code and how you are using it is adequate for the analysis you are performing. This documentation includes the elements of the Evaluation Model development described earlier. Clearly document assumptions and known limitations to help prevent future misuse.
- Maintain the documentation, assessment data, code, and code inputs as living documents under configuration, version, and access control. Maintain backups.
- Perform and document changes under a structured process that under a quality assurance program. Keep version history information.
- Try to maintain it as a living project. Keep it up to date with facility changes and always have someone who is familiar with it and ready to use it. Having two people is better for good knowledge management.

Conclusions

Developing and documenting Evaluation Models using a structured process is beneficial to all people involved in performing and reviewing safety analysis.

- Understanding why it is applicable is important for performing reliable analyses that are technically defensible.
- Understanding the limitations and knowing what the model isn't good for is also important.
- Maintaining the evaluation model as living project is good for knowledge management and ensures it is ready to use when needed.

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References

NRC Regulatory Guide 1.203, “Transient and Accident Analysis Methods”

M. W. Croft, “Advanced Test Reactor Burnout Heat Transfer Tests”, AEC report IDO-24465. Atomic Energy Division, The Babcock and Wilcox Company, January 1964

E. D. Waters, ”Heat Transfer Experiments for the Advanced Test Reactor”, BNWL-216, Pacific Northwest Laboratory, May 1966

R. H. Whittle and R. Forgan, ”A Correlation for the Minima in the Pressure Drop versus Flow-rate Curves for Sub-cooled Water Flowing in Narrow Heated Channels”, NE&D, **6**, pp 88-99 (1967)

P. Saha and N. Zuber, "Point of Net Vapor Generation and Vapor Void Fraction in Subcooled Boiling," Heat Transfer 1974, Proceedings of the 5th International Heat Transfer Conference, Tokyo, Japan, Vol. 4, 175-179, 1974.

E. E. Feldman, “Comparison of the PLTEMP Code Flow Instability Predictions with Measurements Made with Electrically Heated Channels for the Advanced Test Reactor”, ANL/RETR/TM-11-23, June 9, 2011.