Personal memories about the need for and validation of criticality calculations

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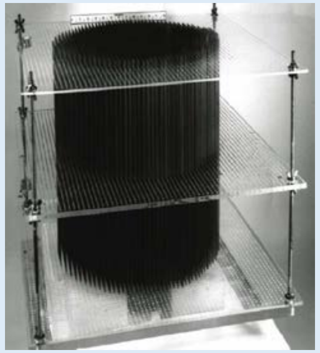
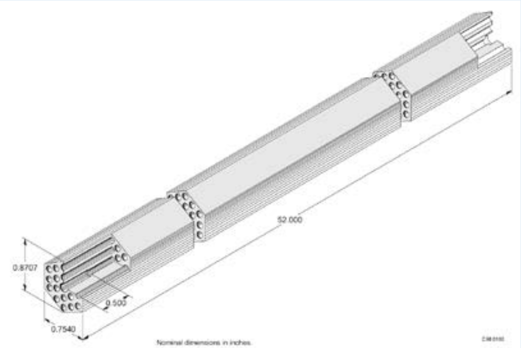
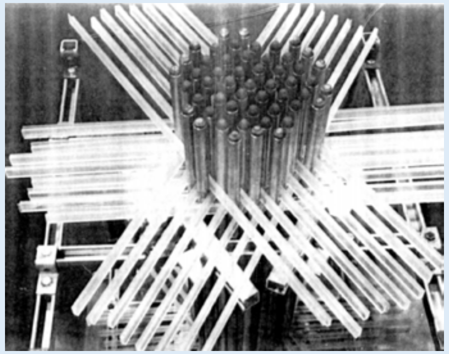
NCSD Panel Session on Past, Present and Future Methods in International Criticality Safety Assessment

ANS 2017 Winter Meeting

1968 – 1970 ORCEF

- ORCEF Radiation Protection Officer – verify & validate measurement calibrations and results regarding worker exposure
- Personal, up-close perspectives about critical systems and the impact of some large and small changes to system parameters
- “Where is the edge/point of criticality” and

  “**To what degree is it known**” – requiring validation of values and errors
- Fascination with the science, technology and modeling of critical and subcritical systems

- Encouraged to transition from health physics to NCS

1970 – 1973 Oak Ridge Y-12 Plant NCS Engineer

- **Safe subcritical** limits for Plant operations based upon reference documents (e.g., Y-1272, TID-7028, TID-7016) and experimental internal Y-12, LASL reports using simplistic 6-factor, but more generally 4-factor, diffusion-theory with geometric buckling

$$k_\infty = \boldsymbol{\eta\epsilon p f}$$

$$k_{eff} = \boldsymbol{\eta\epsilon p f L_f L_t}$$

$$k_{eff} = \frac{\boldsymbol{k_\infty}}{1 + \boldsymbol{M^2 B^2}}$$

$$M^2 = \boldsymbol{\tau} + \boldsymbol{L_d^2}$$

$$B_{g-sph}^2 = \left(\frac{\pi}{r + \boldsymbol{\lambda}}\right)^2$$

$$B_{g-cyl}^2 = \left(\frac{\pi}{h + 2\boldsymbol{\lambda}}\right)^2 + \left(\frac{2.405}{r + \boldsymbol{\lambda}}\right)^2$$

$$B_{g-cub}^2 = \left(\frac{\pi}{x + 2\boldsymbol{\lambda}}\right)^2 + \left(\frac{\pi}{y + 2\boldsymbol{\lambda}}\right)^2 + \left(\frac{\pi}{z + 2\boldsymbol{\lambda}}\right)^2$$

- Analogous approximations
  - Core Density
  - Volume to Surface ratios
  - Fraction critical values

1973 – 1978 Y-12 & K-25 Plants NCS Engineer

- Educated and trained in the use of discrete ordinates, S_n, and Monte Carlo neutron transport computer codes and x-sections
- Given expert guidance for
  - Correlating selected parameters with biases (e.g., H/X)
  - Analyzing correlations and uncertainties
- Challenged to justify computed subcritical values
  - **Methods**
  - **Models**
  - **X-sections**
- Published verification and validation reports for internal use of NCS analyses (Y-1858, Y-1948)

1973 – 1978 Y-12 & K-25 Plants NCS Engineer (cont.)

- Introduction and use of Limiting Surface Density, NB_N^2 method

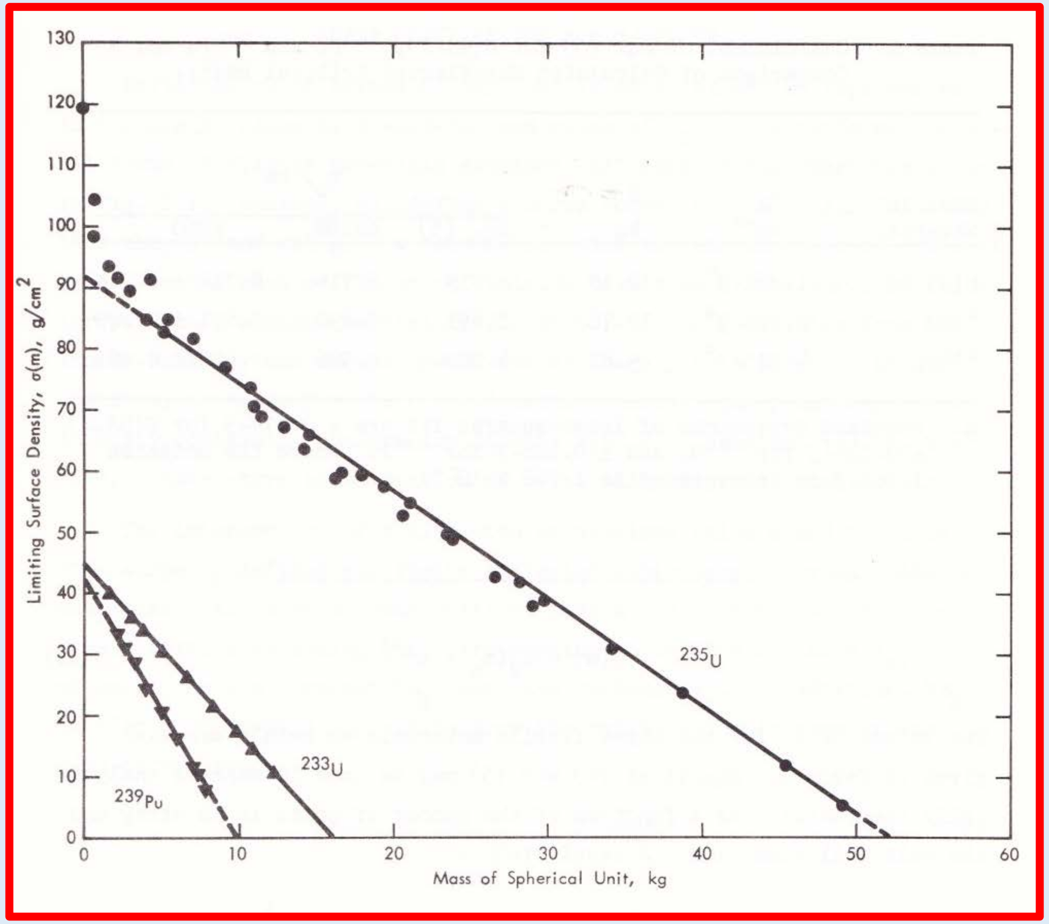
$$NB_N^2 = \frac{3\pi^2 n}{(2a_n)^2}\left\{1 - \left(\frac{4\lambda^2 NB_N^2}{3\pi^2 N}\right)^{\frac{1}{2}}\right\}^2$$

$$NB_N^2 = \frac{3\pi^2 n}{(2a_n)^2}\left(1 - \frac{c}{\sqrt{N}}\right)^2, \quad c = \left(\frac{4\lambda^2 NB_N^2}{3\pi^2}\right)^{\frac{1}{2}} = 0.55 \pm 0.18$$

$$\sigma(a_n) = \frac{nm}{(2a_n)^2}, \quad \sigma(m) = \frac{mNB_N^2}{3\pi^2} = \sigma(a_n)\left(1 - \frac{c}{\sqrt{N}}\right)^2$$

$Given\ N, m,\ m_o\ and\ a_n\ for\ a\ critical\ array, k_{eff}\ for\ a\ larger\ spaced\ array\ is\ determined\ for\ a_* > a_n$

$$k_{eff} \cong \left\{\left(\frac{a_n}{a_*}\right)^2\left(1 - \frac{m}{m_o}\right) + \frac{m}{m_o}\right\}^{\frac{1}{3}}$$



Air spaced units only!!

See ANS Nuclear Technology Vol. 30, No. 2, August 1976

1975 – 1976 U.S. Nuclear, Inc. Consulting NCS Engineer

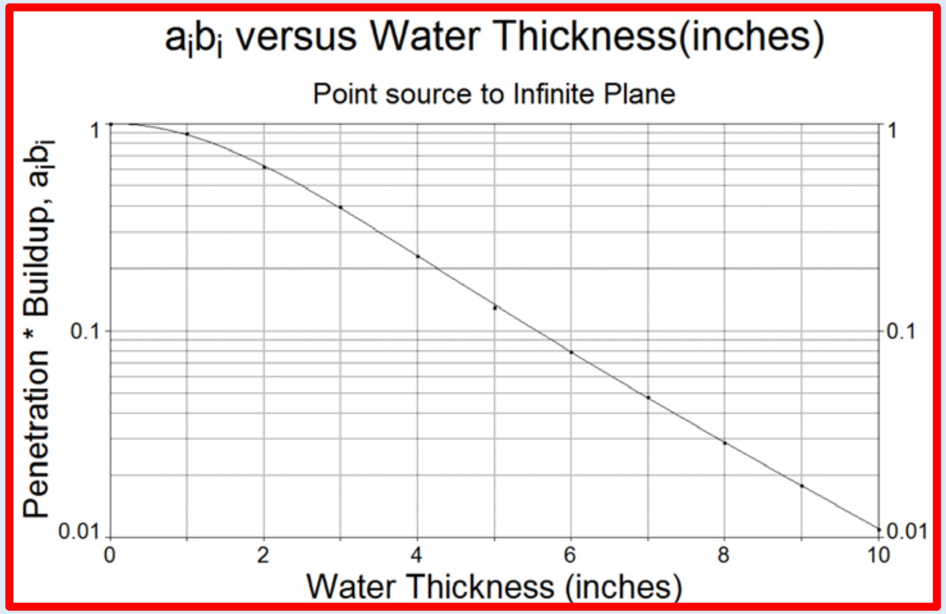
- Contracted to provide facility interaction analysis for License Application
  - No money for KENO II Monte Carlo calculations
  - Utilization of “Extensions of Neutron Interaction Criteria” method (i.e., K-1478) – a spinoff of the “solid angle method” using measured neutron penetration and buildup factors resulting from interstitial water moderation and interaction potentials

$$K_{eff-array} = \frac{k_{eff_{i-f(x,y,z)}}}{(1-v)}$$

$$v = (1 - U_{f\_unit}) \sum_{i-f(x,y,z)} (a_i b_i p_i \Omega_i)$$

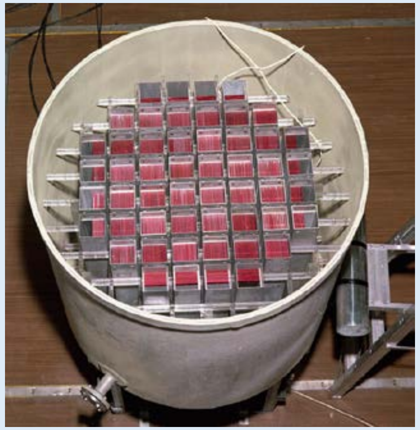
$$p_i = \cos\left(\frac{x\pi}{2W'}\right)\cos\left(\frac{y\pi}{2L'}\right)\cos\left(\frac{z\pi}{2H'}\right)$$

$$a_i b_i = f(water\ thickness)$$



1975 – 1976 U.S. Nuclear, Inc. (cont.)

- Independent validation using water-flooded, variably-pitched MTR fuel element experiments immersed in water



- Maybe it would work?

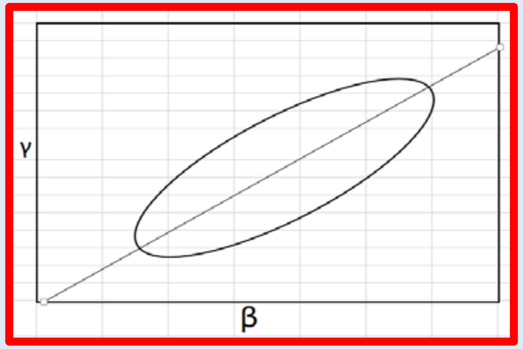
SNML-1315 was issued based upon the Application!!!!

1978 – 1980 Texas Instruments, Inc. SNML-23

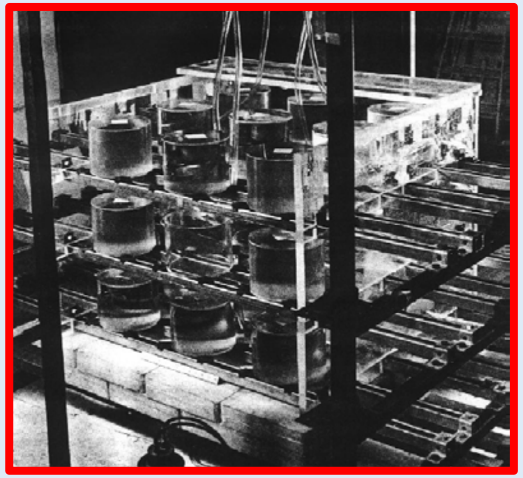
- Managing of NRC Licensing, Nuclear Safety and NMC&A for the TI HFIR Project that manufactured research reactor fuel for DOE supplied reactors
- Developing NMC&A models, HP, and NCS bases for US NRC License application for the research reactor fabrication facility
  - Propagation of chemical, isotopic, mass, and dimensional error models for 1,000's of 7 different plate/fuel-element types
    - **Systematic**
    - **Random**
- Evaluating the impacts and results of models for
  - Security (accountability)
  - Worker health (radiation monitoring, surface & airborne contamination/^{234}U content)
  - Facility interaction subcriticality and criticality indexes (application)
  - Emergency plans (alternative emergency response actions)

1980 – 1984 Y-12 Plant (again)

- HP Department Technical Manager
  - Evaluating and projecting personnel radiation exposures (external & internal)
  - Establishing calibration procedures for new personnel external radiation badges
  - Selecting and using radiation sources and monitoring device, analytical equipment, and services



- NCS Department Head
  - Assessing and establishing acceptably safe subcritical k_{eff} criteria for pseudo-validated arrays of loosely coupled uranyl nitrate columns at the Y-12 Plant
  - Altering plant acceptance criteria



1984 – 2008 Oak Ridge National Laboratory (ORNL)

- 1984 – 1994 ORNL NCS Officer & NCS Program Manager (reviewing, re-evaluating extant historical and evolving safety evaluations)
- 1991 Performing V&V for and documenting the HFIR fresh fuel SARP Chapter 6 NCS
- 1994 – 1996 Co-developing and managing the ORNL NCS Group

1985 – 2008 continued

- 1992 Seeking methods to address the results/concerns identified at the Rocky Flats sponsored Breckenridge CO Workshop on Areas of Applicability Workshop

- 1992 Participating in seminal CSBEP and subsequent ICSBEP meetings – benchmarks specific to validation of methods and defining uncertainties

- 1993 – 1996 Managing US NRC S/U research/development program for predicting U(11)O_2 critical lattices using GLLSM computational analyses by using FSU U(~5% – 21%)UO_2 critical experiments data

- 1997 – 2008 Managing US DOE NCSP S/U research, development, and application program (AROBCAD then TSUNAMI) having general application to energy-group-wise neutron transport code validation specific to ORNL SCALE XSDRN and KENO (pseudo push-back on US DNFSB Rec. 97-2) applied to:
  - Validation using acquired FSU data for SiO_2, RG & WG MOX
  - Design of simulated JIMO space reactor fuel cladding material criticality benchmarks

What we all know?

- We are sensitive to understanding and demonstrating the quality of our safety evaluations
- There are pressures for us to provide improved research and production throughput for more different materials and geometric variations that challenge our existing methods and data validations
- We are unclear about new method unknowns and their cost-to-benefit ratios but their benefits are being revealed with usage and time yielding more knowledge about the validation of our computational safety bases
- We have always been thoughtful about the need for validating our computational methods, whatever they may be, and we continue addressing uncertainties regarding our
    - Methods
    - Data

We are thoughtful

- Care about improving validations of codes and data

  but

  occasionally

- Unclear about the quality of our data and methods

So . . . . . .

- It could be said that we suffer from . . . .

  Sensitivity / **U**ncertainty

I conclude with my best wishes for you to

“Live long **[, *do good*]** and prosper”

Thank you for your attention

Calvin M. Hopper