Criticality Benchmark Analysis of Water-Reflected Uranium Oxyfluoride Slabs

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Outline

- Purpose of evaluation
- Background
- Evaluation process
  - Uncertainty analysis
  - Bias analysis
- Results and Conclusions

Purpose of Evaluation

- ANSI Standard 8.1
  - "Subcritical Limits for Uranium-235 Systems" by Hugh Clark
    - Used "Critical Parameters of Proton-Moderated and Proton-Reflected Slab of U^{235}" by J.K Fox et. al.
- International Criticality Safety Benchmark Evaluation Project (ICSBEP)
- Validation & Verification, Criticality Safety, and Cross Section Data

Experiment Background

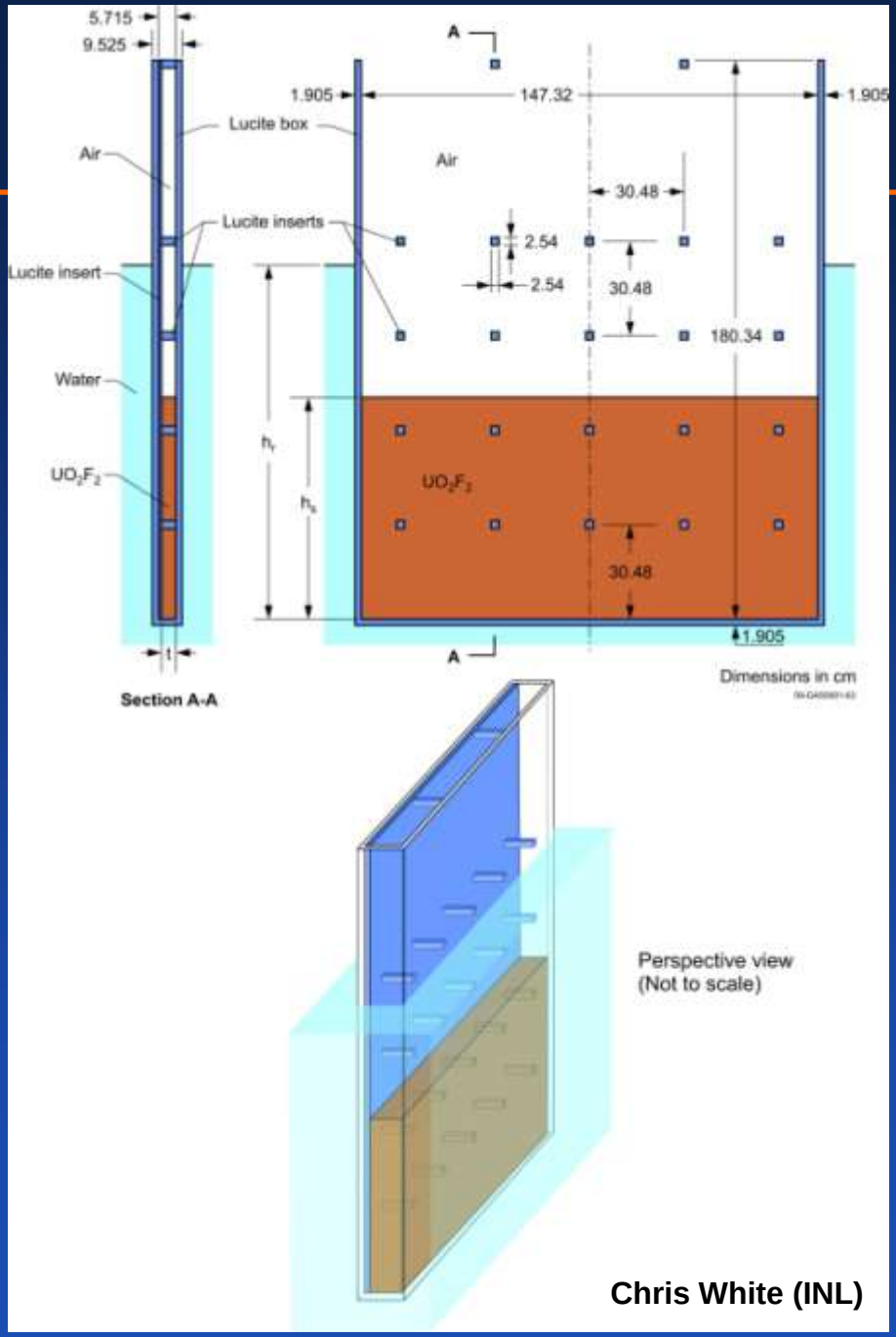
- **Performed:**
  - **1955-56**
  - **Oak Ridge National Laboratory Critical Experiments Facility.**
- **Purpose: minimum critical thickness for infinite slab of UO_2F_2**

Critical Experiments Facility Oak Ridge National Laboratory, 1956

Callihan, A.D., "Critical Experiments and Nuclear Safety At Oak Ridge National Laboratory." ORNL-2087 (1956)

The Experiment

- Materials
  - UO_2F_2 Solution
  - Lucite Box
  - Water Reflected & Moderated
- Slab Thickness Varied, Critical Height Measured



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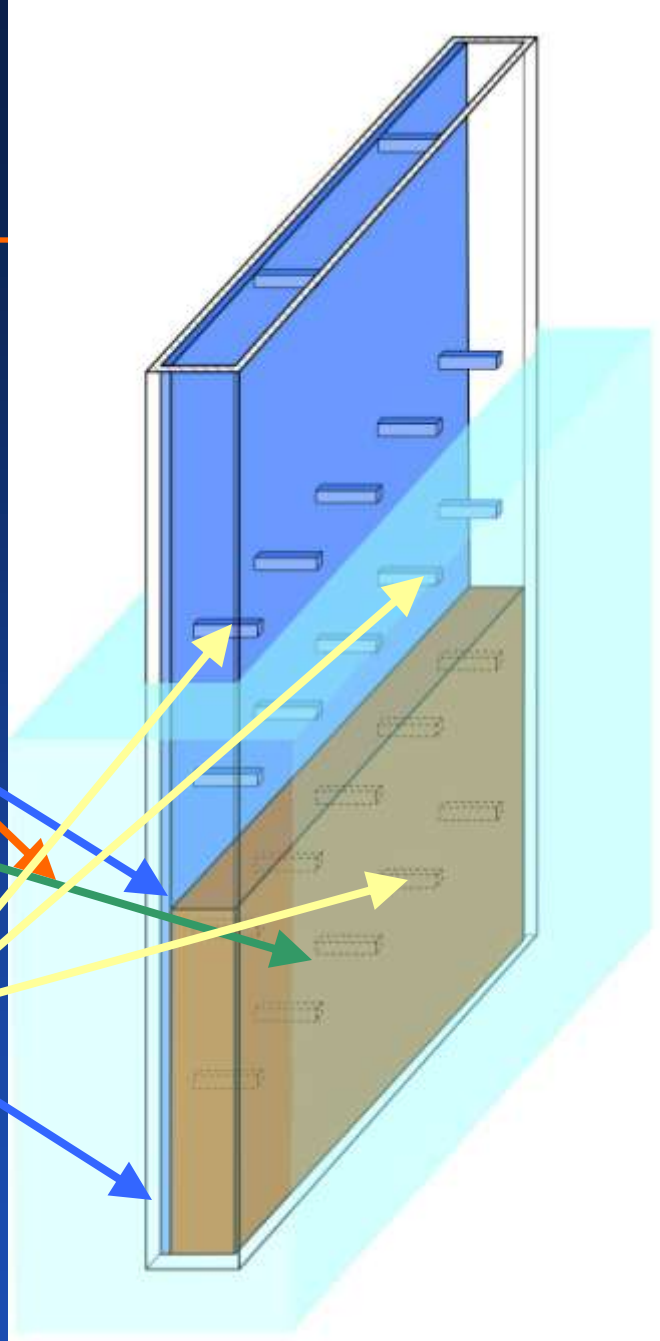
Water Reflector

Lucite Box and Lucite Insert

Uranium Oxyfluoride Solution

Lucite Inserts



Perspective view
(Not to scale)

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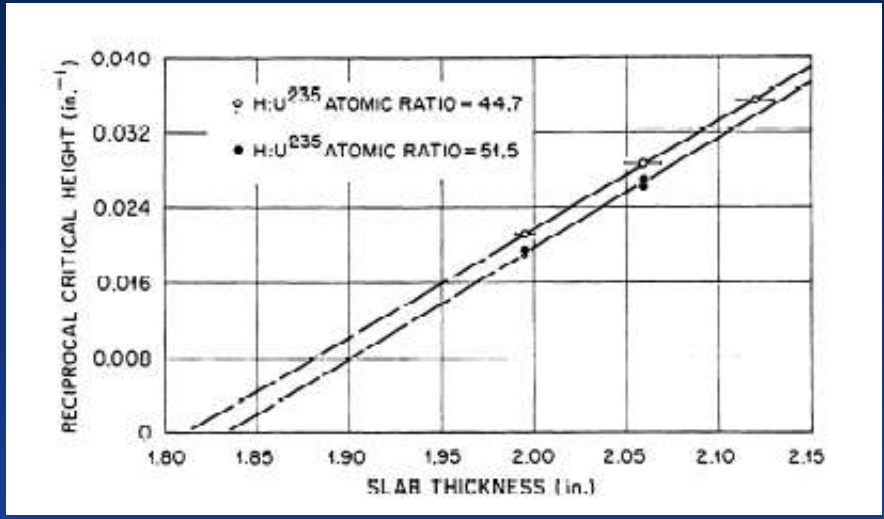
The Experiment

- Issues
  - Slab thickness variation due to hydrostatic pressure
- Results
  - Experimental data allows for extrapolation to minimum slab thickness for infinite height



Extrapolation to Minimum Critical Thickness

J.K Fox, L.W. Gilley, and J.H. Marable, "Critical Paramters of Proton-Moderated and Proton-Reflected Slabs of U^{235}", Nucl. Sci. Eng., 3, 694 (1958)

Benchmark Process

Report Sections

- Section 1 – Experiment
- Section 2 – Uncertainty
- Section 3 – Biases
- Section 4 – Sample Calculations

Uncertainty Assessment

- Perturbation of Parameters
- Difficulties
  - Determining the 1σ uncertainty
  - "Never-Ending" (always coming up with more uncertainties)
- Parameters
  - Solution & Reflector Height
  - Dimensions
  - Material Properties

Uncertainty Analysis Results

Experiment	105	109	110	111	112
Case → / Parameter ↓	1	2	3	4	5
U_{total} Weight Fraction	0.00062	0.00020	0.00018	0.00018	0.00018
Specific Gravity	0.00114	0.00107	0.00106	0.00107	0.00106
Temperature	0.00005	0.00005	0.00005	0.00005	0.00005
Enrichment	0.00013	0.00023	0.00022	0.00020	0.00019
U^{234} Enrichment	0.00211	0.00215	0.00221	0.00203	0.00207
Impurities	0.00023	0.00020	0.00018	0.00022	0.00024
Compounds in Solution	0.00073	0.00065	0.00077	0.00070	0.00060
Lucite Density	0.00021	0.00020	0.00023	0.00020	0.00018
Solution Height	0.00177	0.00055	0.00019	0.00054	0.00015
Reflector Height	0.00005	0.00005	0.00005	0.00005	0.00005
Slab Thickness	0.00155	0.00080	0.00159	0.00161	0.00081
Box Length	0.00002	0.00002	0.00007	0.00002	0.00002
Lucite Thickness	0.00078	0.00074	0.00075	0.00072	0.00075
Total	**0.00360**	**0.00281**	**0.00315**	**0.00306**	**0.00268**

Bias Assessment

- Simplification of model
- Find corresponding Δk_{eff}
- Done systematically

- Simplifications performed
  - No air
  - Insert merged with box in model
  - No out of solution supports
  - Remove box above reflector height
  - Remove impurities in solutions
  - Homogenize supports

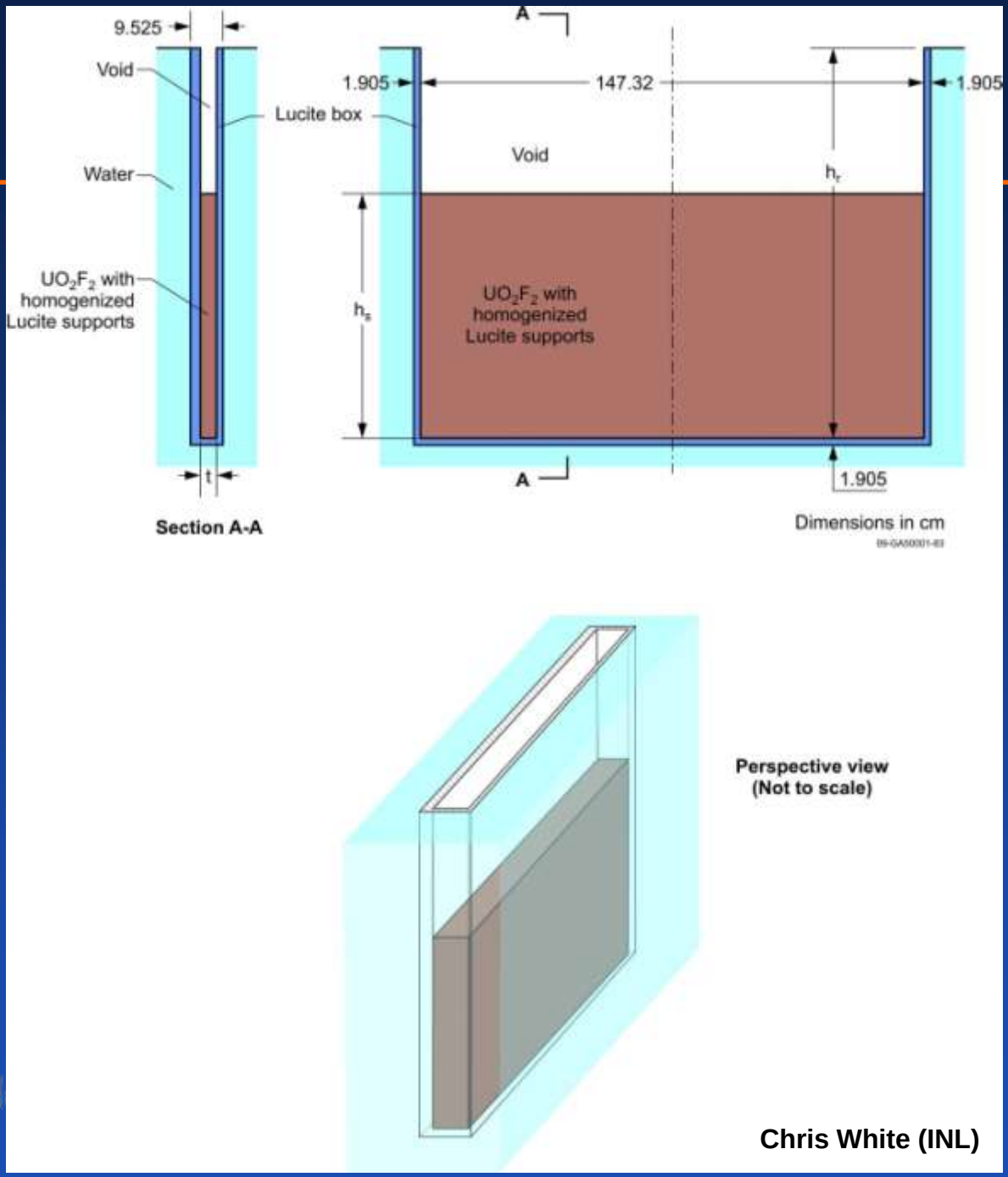
Biases Analysis Results

Case	No Air Δk	No Impurities Δk	Insert Merged with Box Δk	Remove Box above Reflector Height Δk	Homo-genized Supports Δk		Total Simplification Bias [b] Δk
1	-0.00009	0.00013	-0.00005	-0.00011	-- [a]		0.00024
2	0.00006	0.00037	-0.00002	0.00011	0.00070		0.00100
3	0.00005	0.00028	-0.00003	0.00011	0.00062		0.00114
4	-0.00010	0.00028	-0.00009	-0.00016	0.00049		0.00081
5	0.00003	0.00037	0.00014	0.00011	0.00051		0.00101

[a] Case 1 has no Lucite supports.

[b] Bias in k_{eff} when all simplifications are made at the same time.

Simple Model



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Additional Biases

- **Biases not included in the simplified model.**
  - **Replacing Lucite with water**
  - **Homogenizing Lucite into water**

Case	Water Replaces Lucite Box Δk	Homogenized Lucite Box in Reflector Δk
1	-0.02016	-0.01787
2	-0.02213	-0.01960
3	-0.02112	-0.01875
4	-0.02135	-0.01897
5	-0.02234	-0.01991

Other Analysis
Thermal Scattering Treatment

- Thermal scattering treatment adjusts the neutron cross-sections for the upscattering of thermal neutrons based on elemental bonds.
- Light water treatment was used
- Effects of other treatments were analyzed

Case	Benchmark k_{eff}	Light Water[a]	Polyethylene[a]	Solid Methane[a]	Free Gas[a]
1	1.0000	-0.0004	-0.0070	-0.0350	0.0438
2	1.0000	-0.0029	-0.0098	-0.0441	0.0450
3	1.0000	-0.0008	-0.0077	-0.0388	0.0451
4	1.0000	-0.0010	-0.0077	-0.0408	0.0438
5	1.0000	-0.0031	-0.0098	-0.0462	0.0437
Average % Deviation		-0.16%	-0.84%	-4.10%	4.43%

[a] All statistical uncertainties were 0.00005. Δk's are reference to the benchmark k_{eff}. ENDF/B.VII.0 library used.

Results

❖Detailed Model

Case	k_{eff}	uncertainty
1	1.0000	± 0.0036
2	1.0000	± 0.0028
3	1.0000	± 0.0032
4	1.0000	± 0.0031
5	1.0000	± 0.0027

❖Simple Model

Case	k_{eff}	uncertainty
1	1.0002	± 0.0036
2	1.0010	± 0.0028
3	1.0011	± 0.0032
4	1.0008	± 0.0031
5	1.0010	± 0.0027

Sample Calculations

- Run with ENDF/B-VI.8 and –VII.0 libraries

Case	ENDF/B-VI.8			ENDF/B-VII.0		
	k_{eff}	% Deviation	# of σ	k_{eff}	% Deviation	# of σ
1	0.9943	-0.57%	1.69	0.9996	-0.04%	0.11
2	0.9915	-0.85%	3.28	0.9971	-0.29%	1.10
3	0.9936	-0.64%	2.16	0.9992	-0.08%	0.26
4	0.9936	-0.64%	2.25	0.9990	-0.10%	0.34
5	0.9914	-0.86%	3.49	0.9969	-0.31%	1.25

Current Efforts

- Benchmark has been reviewed and improvements to the analysis are being included
  - Reduction of uncertainty in Lucite thickness and ^{234}U content
- Revised benchmark to be presented before the ICSBEP technical working group May 2010 in Slovenia.
  - To be included in the September 2010 edition of the ICSBEP Handbook

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Questions?