Monte-Carlo CIPS and CILC assessment to OPR1000 with HIPER16

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Contents

I. Introduction

CIPS (Crud Induced Power Shift)

- Cause : subcooled nucleate boiling, corrosion products, boron, etc.
- The phenomenon of the axial power distribution bias downward due to the accelerated deposition of boron compounds and crud at the upper part of the cladding
- Assessment : Calculating the amount of the boron deposition in core
- Monte-Carlo simulation : Estimating uncertainties of BOA code input variables
- Threshold

- Mild CIPS : 230 ~ 450 g (0.5 lbm ~ 1.0 lbm)

- Severe CIPS : 450 g ~ (1.0 lbm ~)

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I. Introduction

CILC (Crud Induced Localized Corrosion)

- The phenomenon of accelerated corrosion of the cladding surface due to the crud deposition
- Assessment : Crud deposition
  - Tier 1 : 1/4 Assembly scale
  - Tier 2 : Subchannel scale
  - Tier 4 : 20 segmented fuel rod surface scale
- Threshold
  - Crud thickness 115.0 ± 12.5 microns (4.5 ± 0.5 mils)

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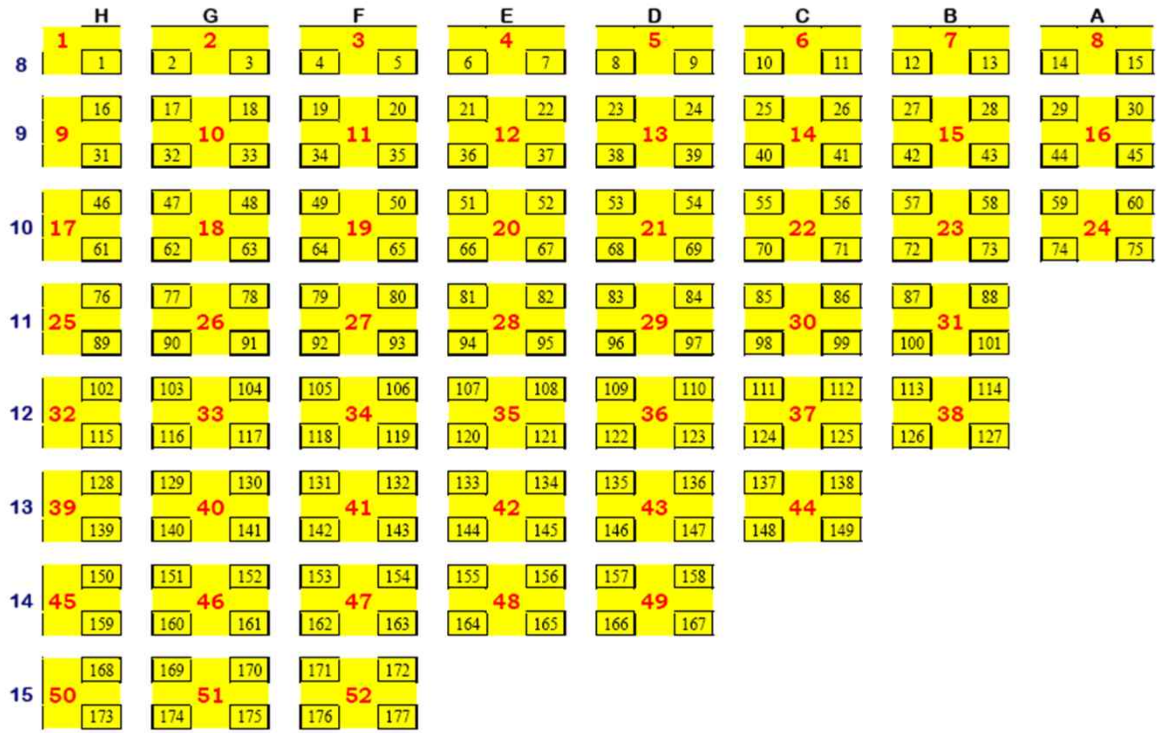
I. Introduction

Analyzing Variables

- Number of FAs in Core : 177
- Number of Grid : 13
- Axial length : 165 in



ASSESSMENT Tool

- BOA Code (EPRI, December 2017)
- New fuel location
- AOA interface data
- Lithum/Boron concentration
- RCS Zinc Scenario/Strategy Data

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I. Introduction

Calculation Case

- No reactor trip & No zinc injection (NTNZ)
- Reactor trip & No zinc injection (TNZ)
- Reactor trip & Zinc injection (TZ)

- Using ultrasonic fuel cleaning (BOA input variable - FM : 0.4452)

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II. Monte-Carlo CIPS

Parameter types related to CRUD deposition

- Overall crud source distribution
- In-core crud distribution
- Operation

Descriptions	Dist.	Lower Bound (Fraction of Nominal)	Upper Bound (Fraction of Nominal)	Technical Basis Description
Nickel Alloy Corrosion Rate	Uniform	0.50	1.25	Figure 4-2 in Section 4.1.1 (Ref. [3])
Stainless Steel Corrosion Rate	Uniform	0.50	1.25	Ref. [4]
Crud Mapping Multiplier	Uniform	0.75	1.25	Ref. [5]
Dittus-Boelter Coefficient	Normal	0.70	1.30	Section 2.2.2 (Ref. [3])
Particle Deposition Coefficient	Uniform	0.10	1.00	Section 2.5.3 (Ref. [3])
Particle Release Coefficient(Core)	Uniform	0.33	1.67	Section 2.5.4 (Ref. [3])
Particle Release Coefficient(Other)	Uniform	0.33	1.67	Section 2.5.4 (Ref. [3])
Particle Mass Transfer Coefficient(Core)	Uniform	0.33	1.67	Section 2.5.4 (Ref. [3])
Local Heat Flux	Normal	0.997	1.003	TH Code Sensitivity
Local Pressure	Uniform	0.993	1.007	TH Code Sensitivity
Local Coolant Temperature	Normal	0.997	1.003	TH Code Sensitivity
Local Mass Flux	Normal	0.990	1.010	TH Code Sensitivity

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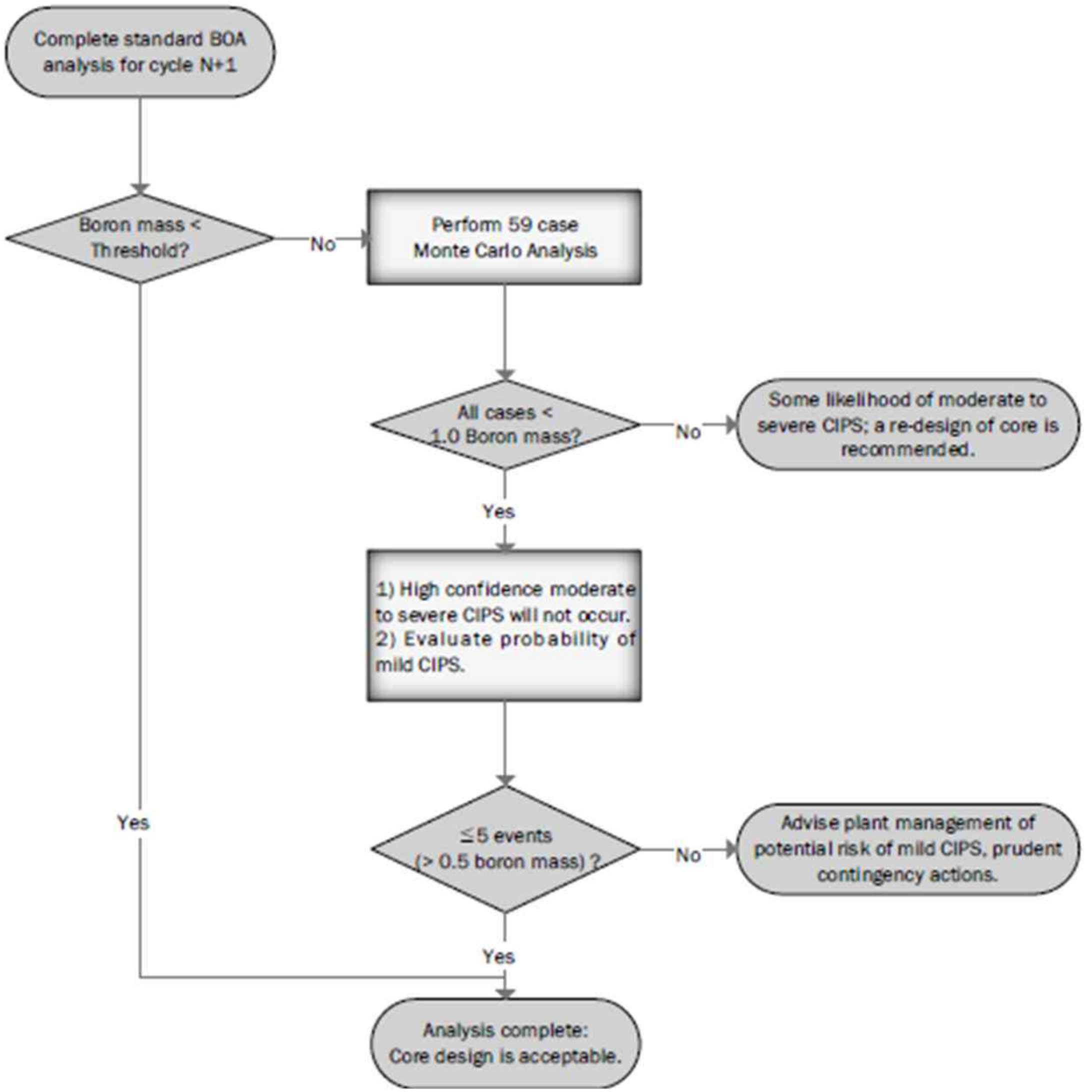
II. Monte-Carlo CIPS



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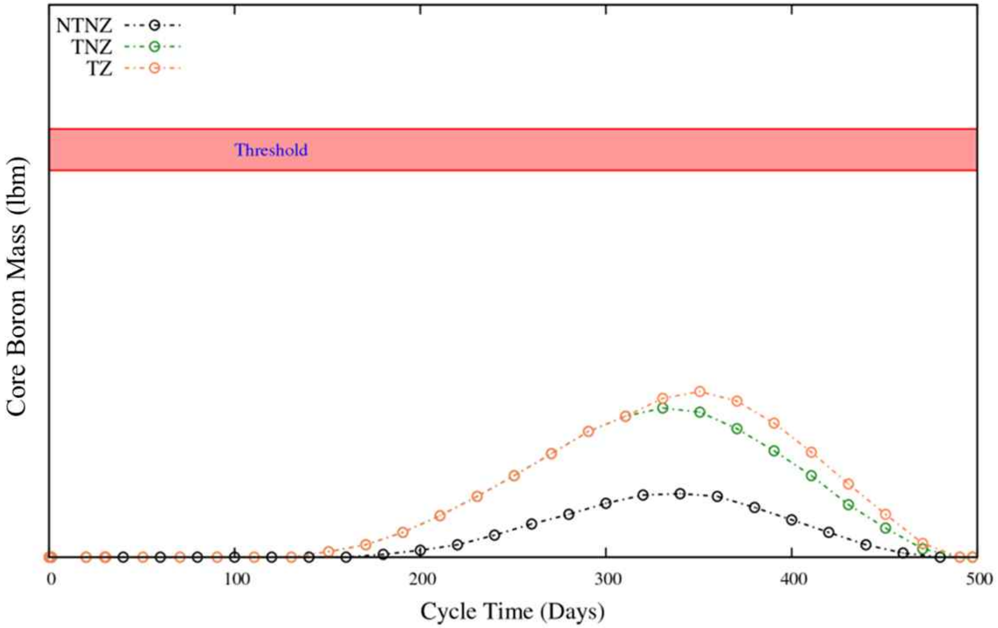
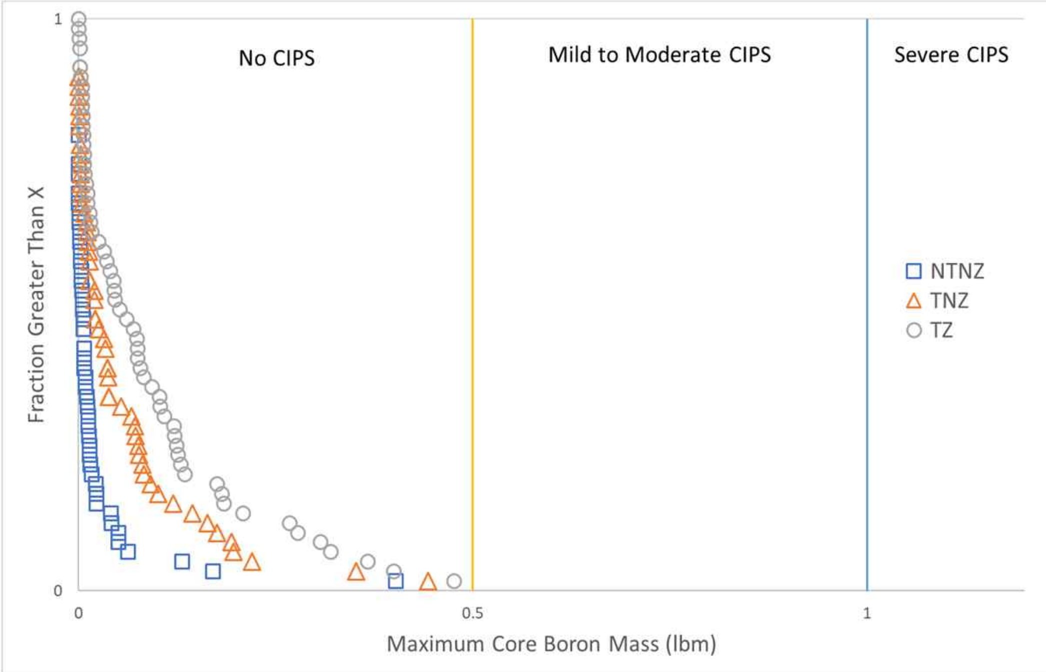
II. Monte–Carlo CIPS

- Core Boron Mass

Not applied Monte-Carlo CIPS methodology



The results of Monte-Carlo CIPS



	Severe CIPS	Mild to Moderate CIPS
NTNZ	0 severe CIPS → Satisfied 95/95	0 mild CIPS → mild CIPS occurrence probability under 10 %
TNZ		
TZ		

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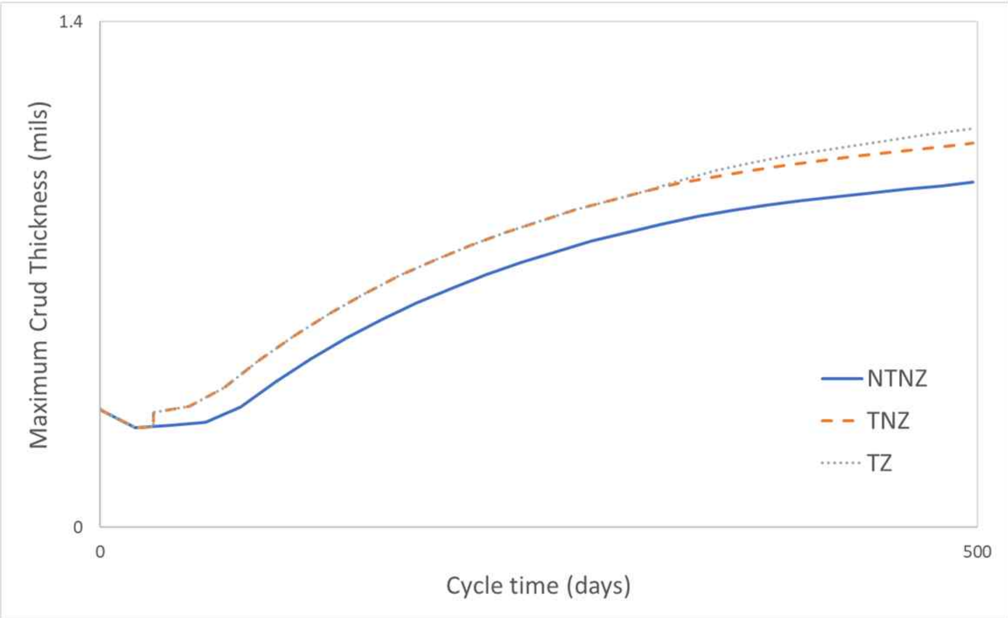
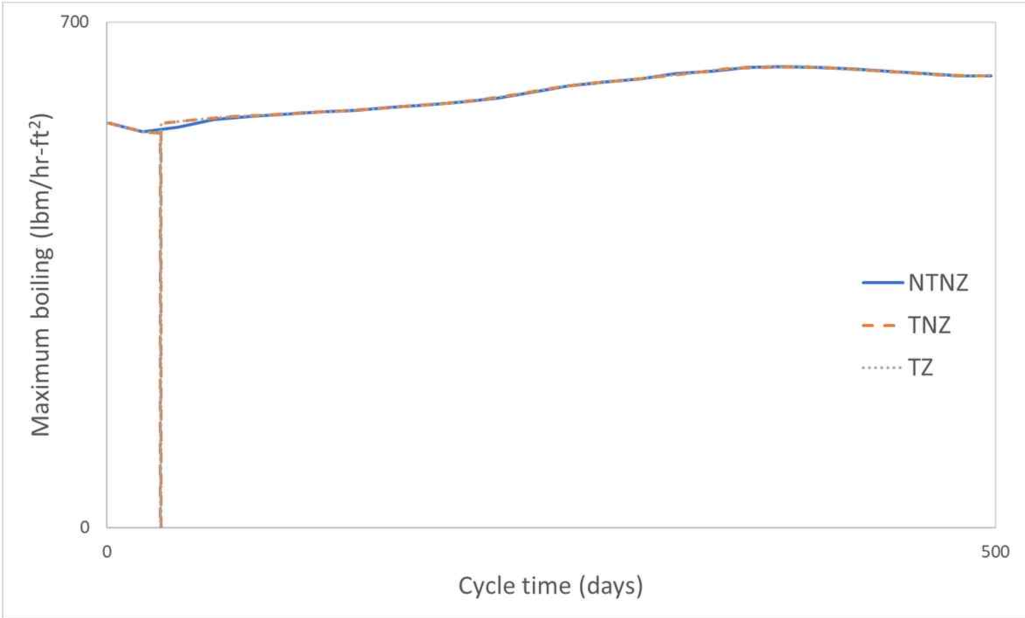
III. CILC

When CILC assessment is required

- In case of maximum crud thickness over 3 mils (75 microns) or 0.75 mils (19 microns) over than previous cycle
- In case that a period of zero mass evaporation rate is greater than 75 % of the total cycle
- In case that utility desire to CILC risk assessment





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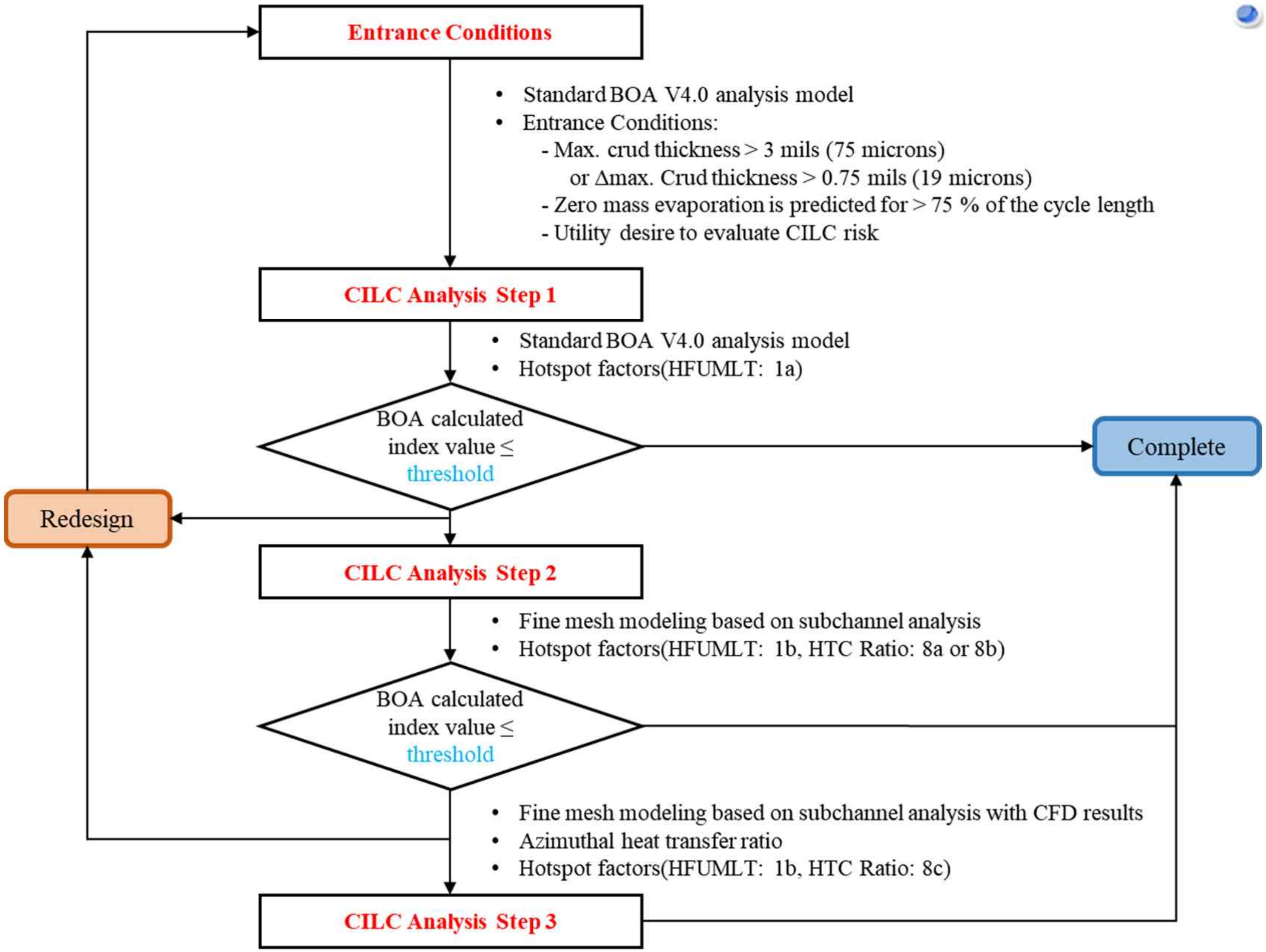
III. CILC

Flow chart of CILC assessment



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III. CILC

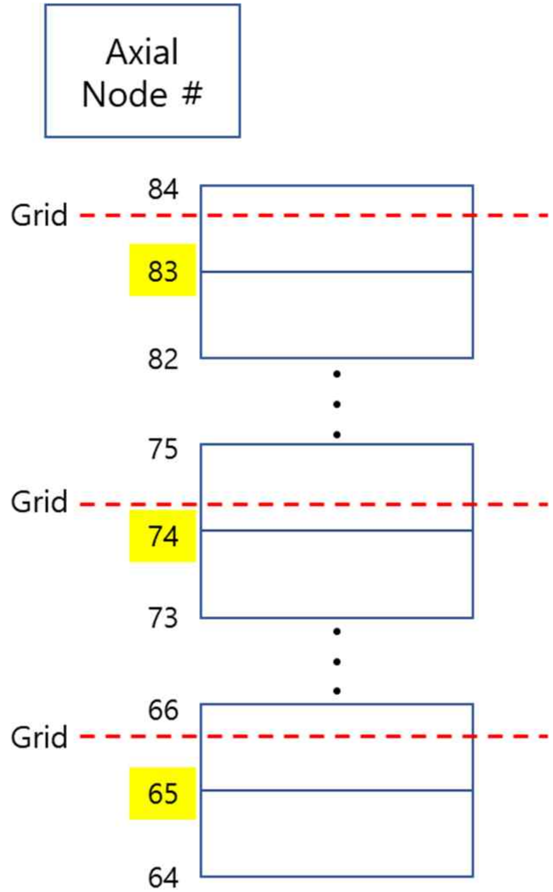
CILC Analysis Step 1 : Tier 1 BOA Analysis with Hotspots

Prepare BOA Code Input

- Set the hotspot location
  - hotspot : Node right under the grid more than 100 in. from the start of the heating length

- Input the hotspot factors

- Applying the same hotspot factor to conservatively evaluate crud deposition for all assemblies



HIPER16 hotspot location

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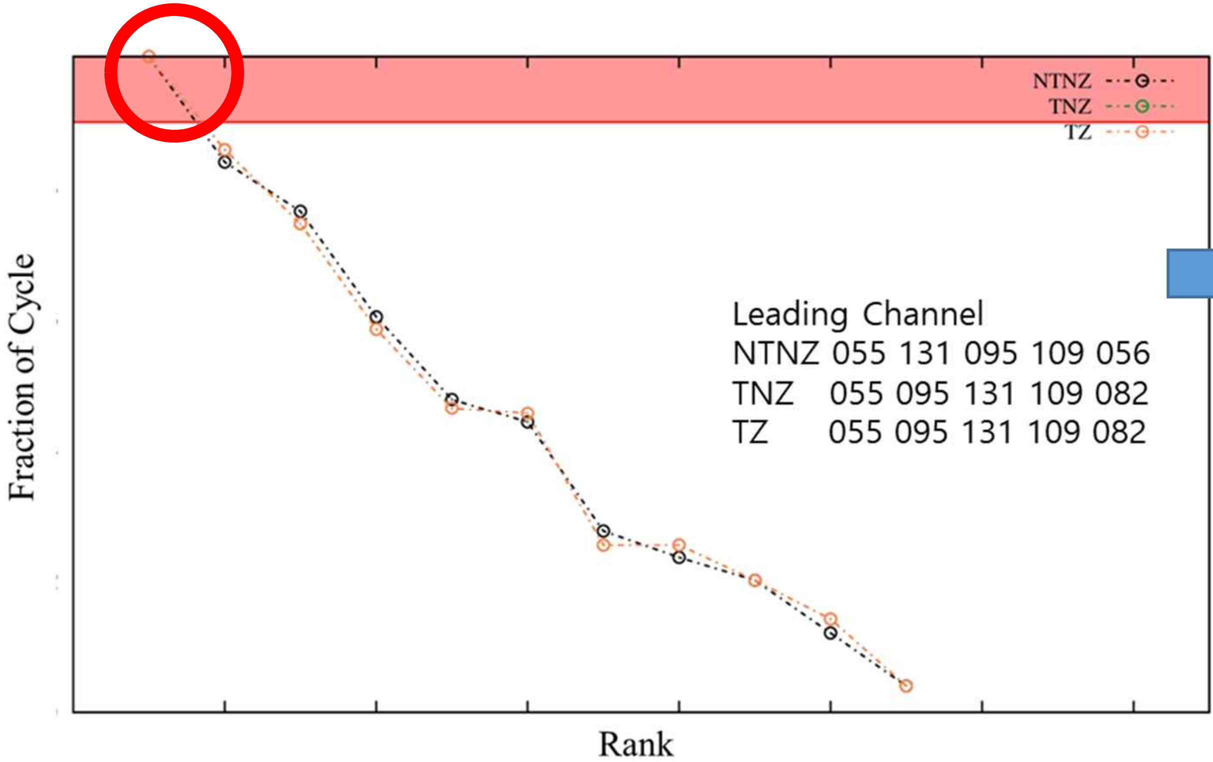
III. CILC

CILC Analysis Step 1 : Tier 1 BOA Analysis with Hotspots

- Leading Channel Technique

The period being in top 5 which mass evaporation rate of specific channel > 90 % of total cycle → Increasing the CILC occurrence



→ Performed CILC Analysis Step 2(Tier 2)

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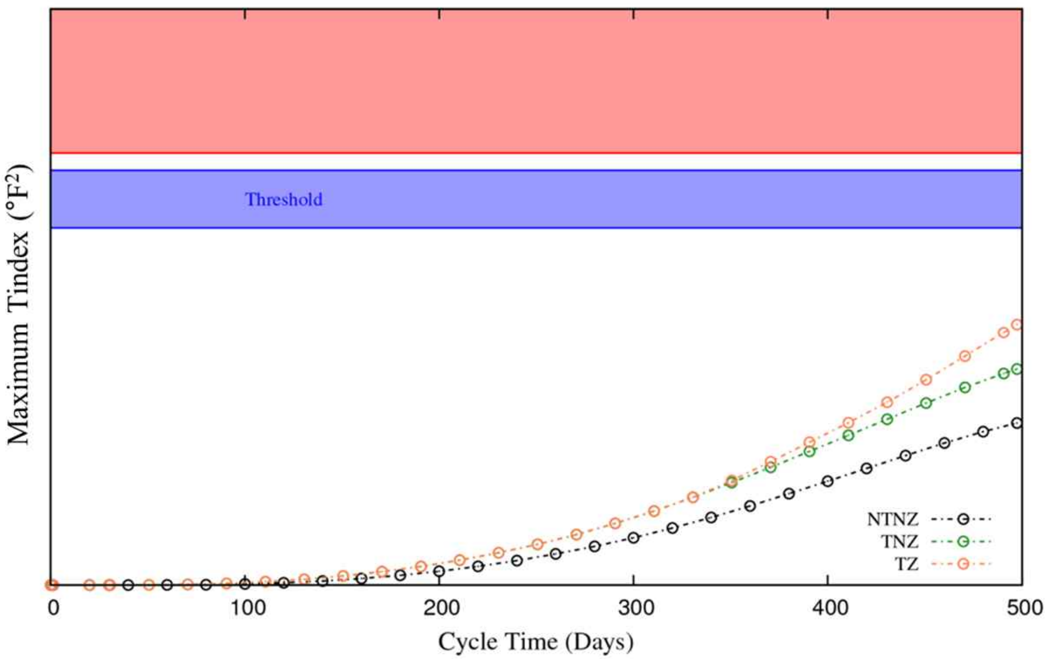
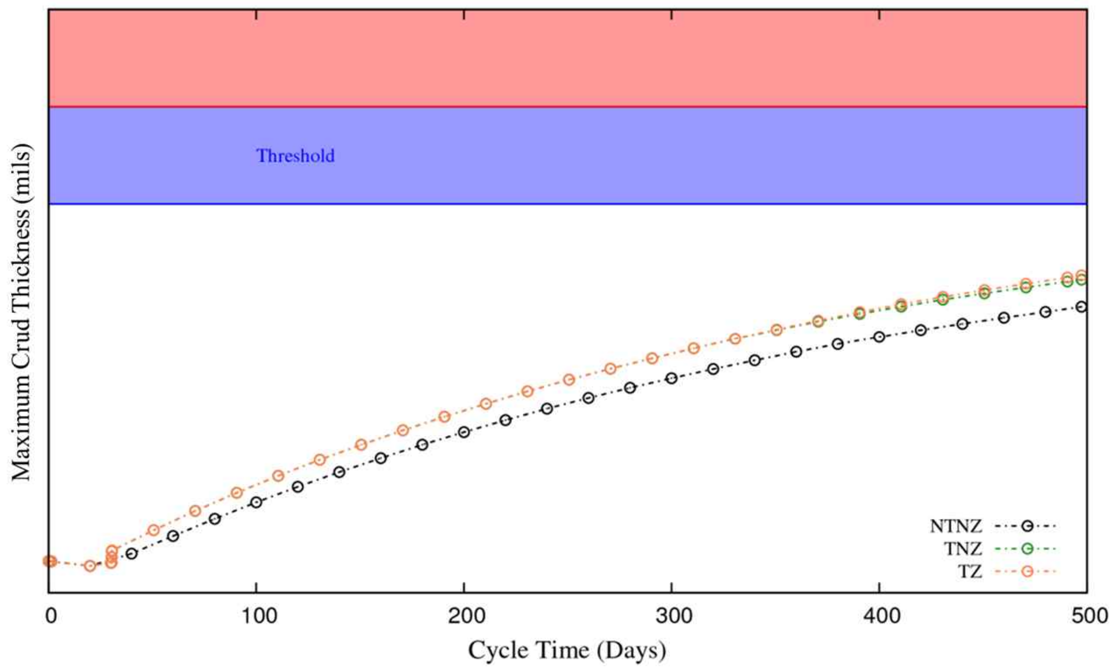
III. CILC

CILC Analysis Step 1 : Tier 1 BOA Analysis with Hotspots





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III. CILC

CILC Analysis Step 2 : BOA Tier 2 Subchannel Analysis

- Using fine mesh modeling
  - Target node selection

1.2	1.1	1.1	1.2	1.2	1.1	1.2	1.2	1.2	1.1	1.1	1.2	1.0	0.5	0.2
1.1	1.1	1.1	0.9	0.9	1.2	1.3	1.3	1.3	1.2	1.1	1.3	1.0	0.5	0.2
1.1	1.1	1.1	0.9	0.9	1.2	1.3	1.3	1.3	1.2	1.2	1.3	1.0	0.5	0.2
1.2	0.9	0.9	1.0	1.1	1.2	1.3	1.3	1.2	1.3	1.3	1.2	0.9	0.4	0.2
1.2	0.9	0.9	1.1	1.2	1.3	1.3	1.3	1.2	1.3	1.2	1.2	0.9	0.4	0.2
1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.2	1.1	1.1	1.2	0.8		
1.2	1.3	1.3	1.3	**1.3**	1.3	1.3	1.3	1.2	1.1	1.0	1.0	0.7		
1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.0	0.6	0.3		
1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.3	1.2	1.0	0.8	0.4	0.2		
1.1	1.2	1.2	1.3	1.3	1.1	1.1	1.2	1.0	0.6	0.4				
1.1	1.1	1.2	1.3	1.2	1.1	1.0	1.0	0.8	0.4	0.2				
1.2	1.3	1.3	1.2	1.2	1.2	1.0	0.6	0.4						
1.0	1.0	1.0	0.9	0.9	0.8	0.7	0.3	0.2						
0.5	0.5	0.5	0.4	0.4										
0.2	0.2	0.2	0.2	0.2										

Target

- **Assembly with the highest radial power distribution**
- Assemblies with the leading channels of Tier 1

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III. CILC

CILC Analysis Step 2 : BOA Tier 2 Subchannel Analysis

- Using fine mesh modeling
  - Target node selection

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
76	77	78	79	80	81	82	83	84	85	86	87	88		
89	90	91	92	93	94	95	96	97	98	99	100	101		
102	103	104	105	106	107	108	109	110	111	112	113	114		
115	116	117	118	119	120	121	122	123	124	125	126	127		
128	129	130	131	132	133	134	135	136	137	138				
139	140	141	142	143	144	145	146	147	148	149				
150	151	152	153	154	155	156	157	158						
159	160	161	162	163	164	165	166	167						
168	169	170	171	172										
173	174	175	176	177										

: Leading Channels(NTNZ, TNZ, TZ)
: Leading Channels(TNZ, TZ)
: Leading Channels(NTNZ)
: Final Selection for Tier 2

Target

- Assembly with the highest radial power distribution
- **Assemblies with the leading channels of Tier 1**

Selected total 20 nodes for CILC Tier 2 Analysis

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III. CILC

CILC Analysis Step 2 : BOA Tier 2 Subchannel Analysis

- Using fine mesh modeling
  - Example of AOA files for fine mesh modeling analysis

Chn No.	Axial node No.	Rod No.	HT surf. No.	Axial elevation	Heat flux	Local press.	Local fluid temp.	Local mass flux	Hydraulic diameter	Heat transfer ratio	Surface area fraction
55	12	1	1	19.3085	15.5865	2270.79	566.26	1.8181	0.6423	1.00	0.004237
55	12	1	2	19.3085	15.5865	2270.78	566.06	2.2289	0.4977	1.00	0.004237
55	12	1	3	19.3085	15.5865	2270.78	565.82	2.2767	0.6423	1.00	0.004237
55	12	1	4	19.3085	15.5865	2270.79	566.05	1.9028	0.8111	1.00	0.004237
55	12	2	1	19.3085	17.2068	2270.78	566.06	2.2289	0.4977	1.00	0.004237
55	12	2	2	19.3085	17.2068	2270.78	566.14	2.3842	0.4977	1.00	0.004237
55	12	2	3	19.3085	17.2068	2270.78	565.86	2.4311	0.6423	1.00	0.004237
55	12	2	4	19.3085	17.2068	2270.78	565.82	2.2767	0.6423	1.00	0.004237

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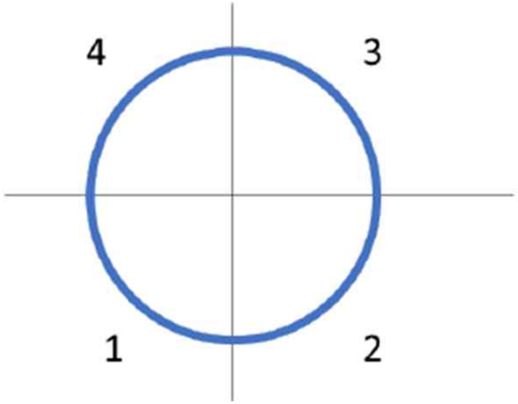
III. CILC

CILC Analysis Step 2 : BOA Tier 2 Subchannel Analysis

- Using fine mesh modeling

  - Example of AOA files for fine mesh modeling analysis

Chn No.	Axial node No.	Rod No.	HT surf. No.	Axial elevation	Heat flux	Local press.	Local fluid temp.	Local mass flux	Hydraulic diameter	Heat transfer ratio	Surface area fraction
55	12	1	1	19.3085	15.5865	2270.79	566.26	1.8181	0.6423	1.00	0.004237
55	12	1	2	19.3085	15.5865	2270.78	566.06	2.2289	0.4977	1.00	0.004237
55	12	1	3	19.3085	15.5865	2270.78	565.82	2.2767	0.6423	1.00	0.004237
55	12	1	4	19.3085	15.5865	2270.79	566.05	1.9028	0.8111	1.00	0.004237
55	12	2	1	19.3085	17.2068	2270.78	566.06	2.2289	0.4977	1.00	0.004237
55	12	2	2	19.3085	17.2068	2270.78	566.14	2.3842	0.4977	1.00	0.004237
55	12	2	3	19.3085	17.2068	2270.78	565.86	2.4311	0.6423	1.00	0.004237
55	12	2	4	19.3085	17.2068	2270.78	565.82	2.2767	0.6423	1.00	0.004237



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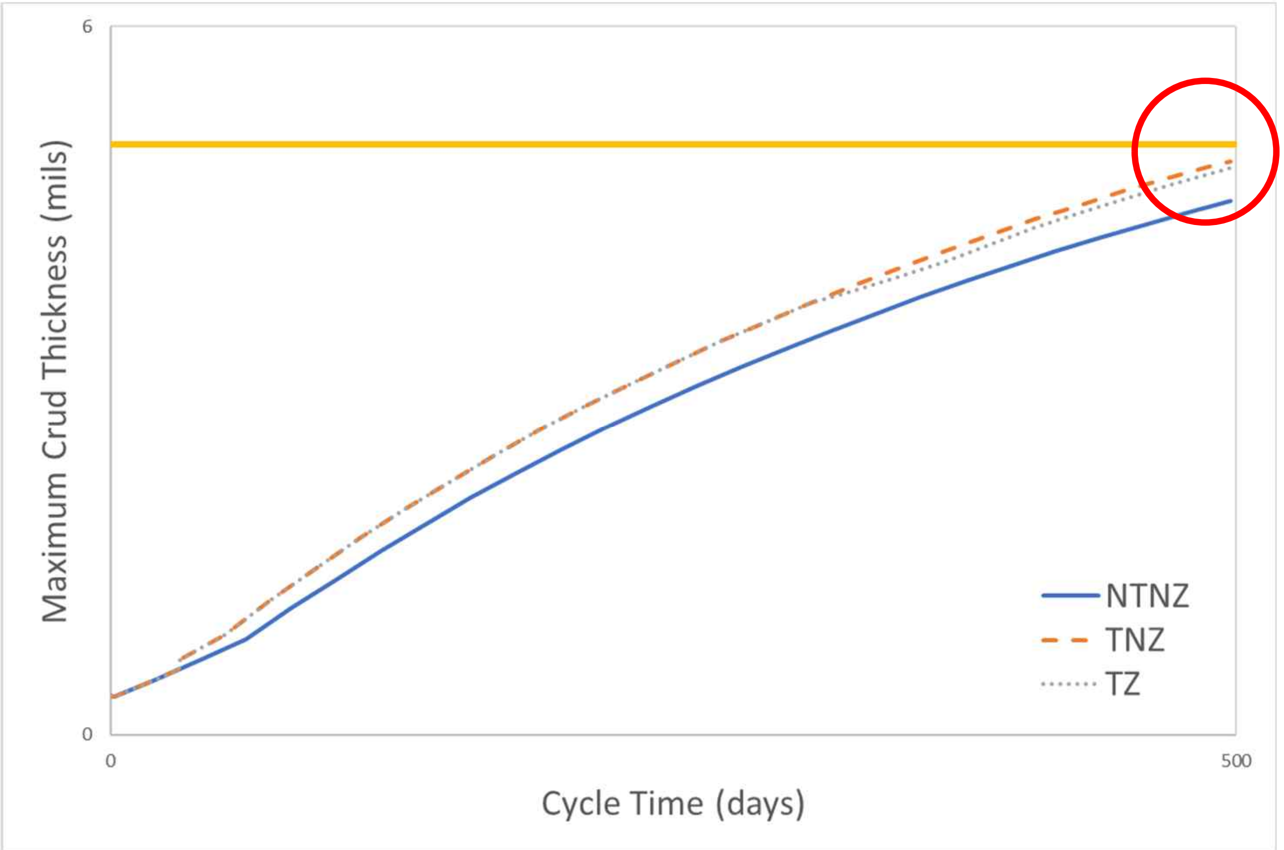
III. CILC

CILC Analysis Step 2 : BOA Tier 2 Subchannel Analysis



Crud thickness threshold

115.0 ± 12.5 microns (4.5 ± 0.5 mils)

➡ Satisfied

Crud thickness > 5 mils

➡ Need to perform Tier 4

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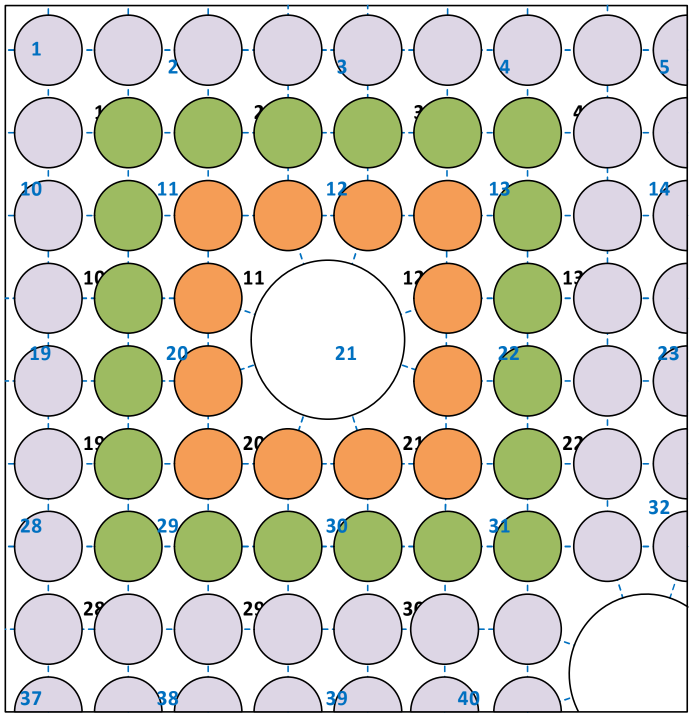
III. CILC

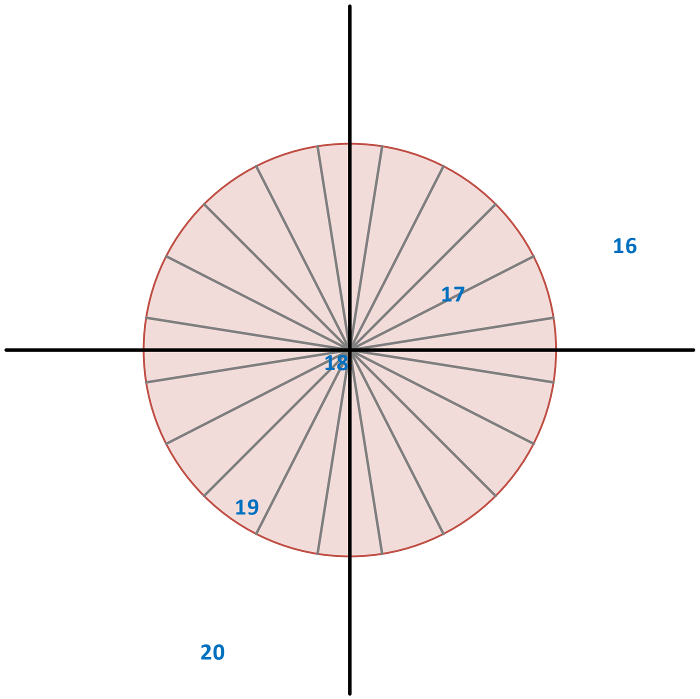
CILC Analysis Step 3 : BOA Tier 4 Analysis

- CFD Analysis

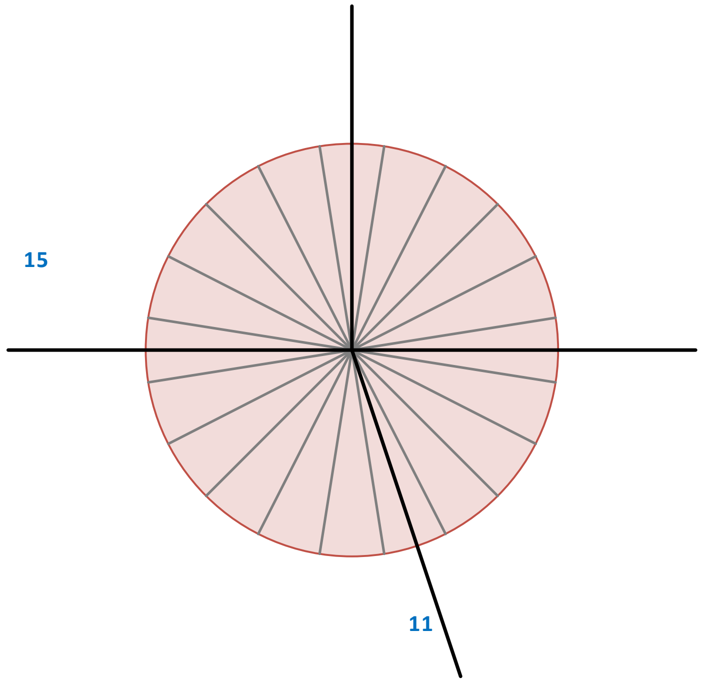
  using 20 azimuthal CFD determined heat transfer coefficients with the subchannel



8.5 × 8.5 modeling



Rod index of ordinary subchannel



Rod index of near the guide tube

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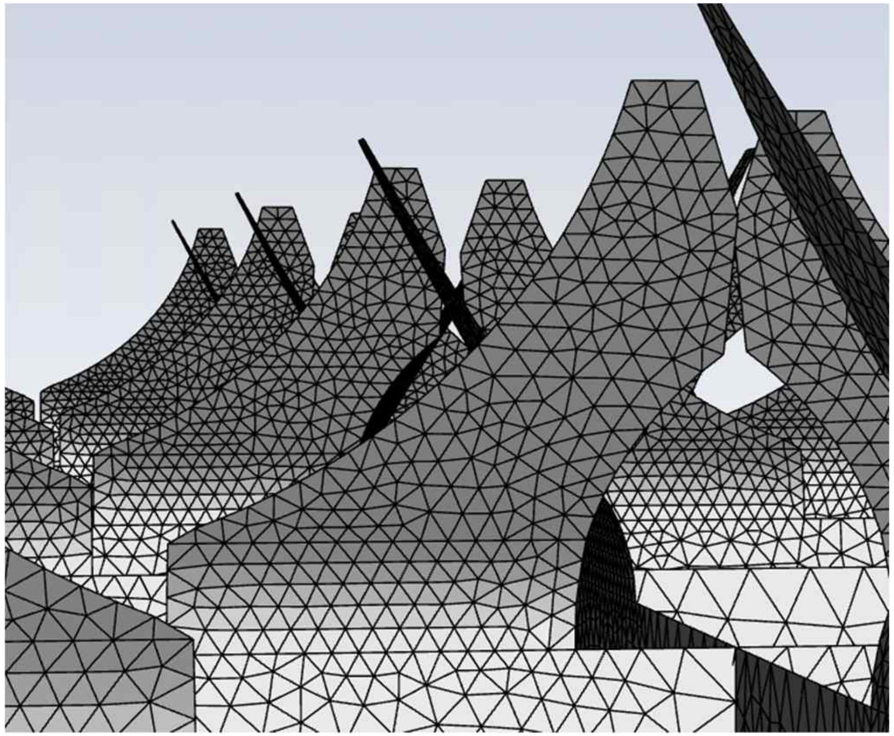
III. CILC

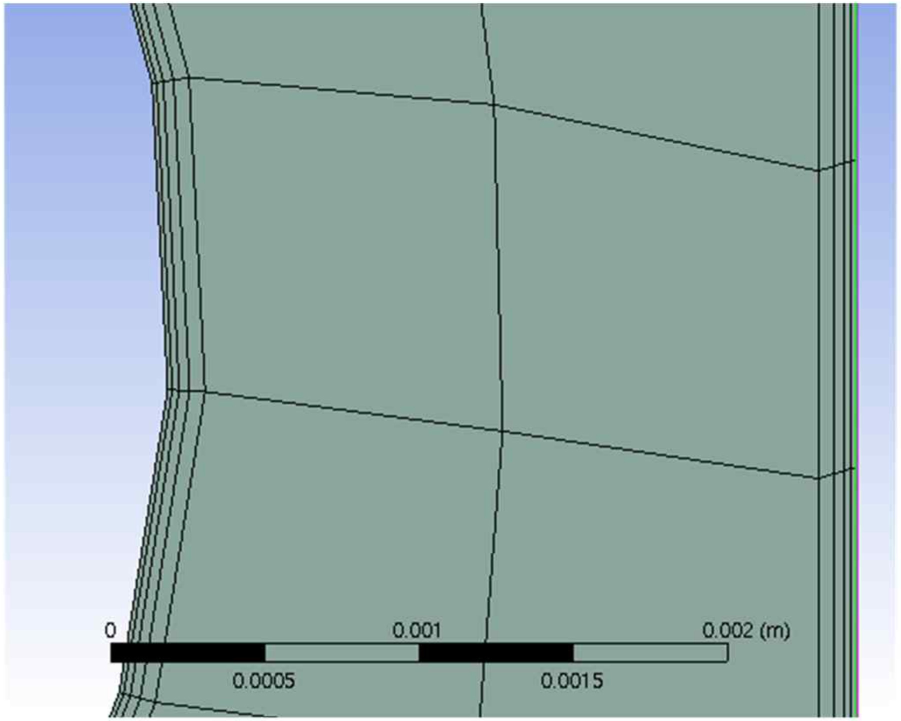
CILC Analysis Step 3 : BOA Tier 4 Analysis

- CFD Analysis

  Program : Ansys Fluent (Version 2020 R2)



Mesh of mixing vanes



Near wall treatment

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III. CILC

CILC Analysis Step 3 : BOA Tier 4 Analysis

- Heat transfer rate

$$HTR_{i,j,k,l} = \frac{HTC_{CFD_{i,j,k,l}}}{HTC_{i,j,k,l}} = \frac{\dfrac{q'_{i,j,k,l}}{T_{CFD_{i,j,k,l}} - T_{b_{i,j,k,l}}}}{HTC_{i,j,k,l}}$$

where, HTR : Heat transfer coefficient ratio

HTC : Heat transfer coefficient [Btu/hr-ft^2-°F]

I : ¼ assembly ID

j : axial node ID

k : rod ID

l : surface ID

q'' : heat flux [Btu/hr-ft^2]

T_{CFD} : surface temperature calculated by CFD [°F]

T_b : bulk temperature calculated by subchannel analysis code [°F]

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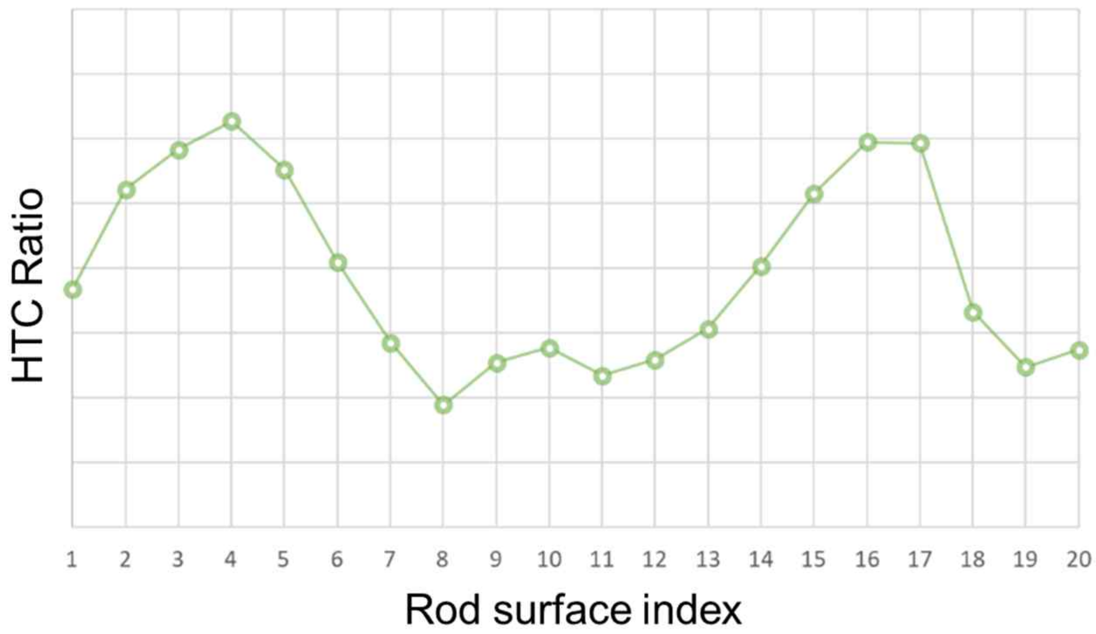
III. CILC

CILC Analysis Step 3 : BOA Tier 4 Analysis

- Heat transfer rate example



- Calculated all rods in 8.5x8.5 model
- Difficulty in deriving a representative distribution because of flow mixing by mixing vane
- For each rod where large amount of crud are expected to be deposited, the appropriate HTR should be applied.

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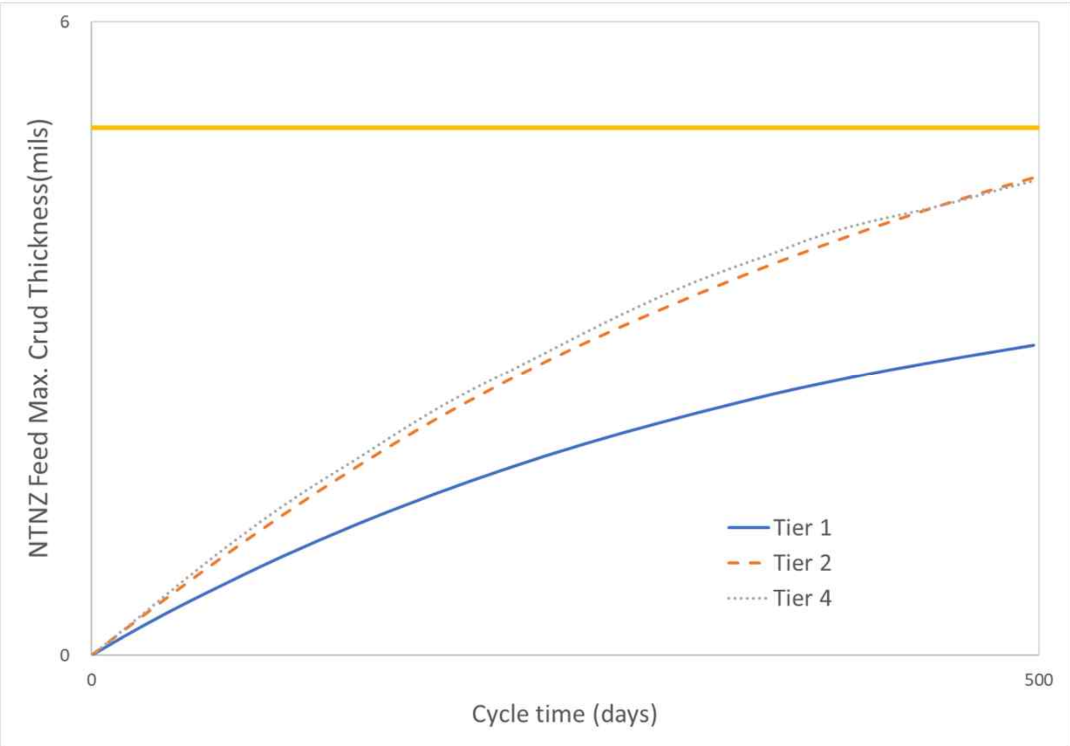
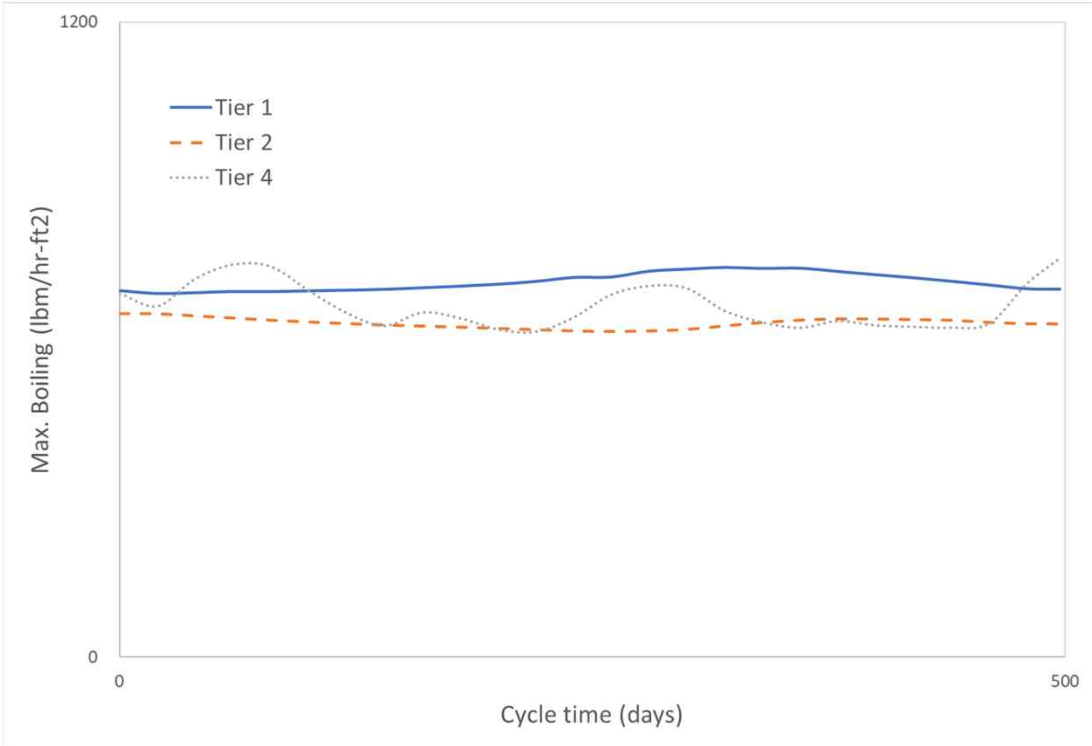
III. CILC

CILC Analysis Step 3 : BOA Tier 4 Analysis





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IV. Summary

Calculation Cases

- No reactor trip & No zinc injection (NTNZ)
- Reactor trip & No zinc injection (TNZ)
- Reactor trip & Zinc injection (TZ)

Monte-Carlo CIPS

- Maximum core boron mass not exceeding 0.5 lbm
- Maximum crud thickness not exceeding 3 mils
- Period of zero mass evaporation rate are less than 75 % of the total cycle

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IV. Summary

CILC Tier 1 and 2

- Tier 1 : The period being in top 5 which mass evaporation rate of specific channel > 90 % of total cycle
- Tier 2 : Maximum crud thickness not exceeding 5 mils

CILC Tier 4

- CFD Analysis for HIPER16 8.5×8.5 model
- Performed the Tier 4 assessment about NTNZ case
- **Next Step**

  CFD Analysis about full scale model and calculating all rods heat transfer coefficient

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