A Borated-Alumimum Cask Design for Used Fuel Cooling

Updates to modeling, simulation, and design

A Center for Advanced Energy Studies Collaboration
University of Idaho-Idaho Falls
Boise State University
with
Sakae Casting USA, LLC

Bob Borrelli
University of Idaho-Idaho Falls
Center for Advanced Energy Studies
@TheDoctorRAB

American Nuclear Society Annual Meeting
09-13, June 2019
Minneapolis, MN

The starting 5

Prof. Bob Borrelli, University of Idaho-Idaho Falls (CAES) - ME!

Prof. Richard N. Christensen, University of Idaho-Idaho Falls (CAES)
Nuclear Engineering Program Director

Prof. Brian Jaques - Boise State Univeristy

Mr. Takashi Suzuki - CEO - Sakae Casting

Mr. Mark Delligatti, President - Table Rock, LLC
30 years experience in licensing casks at NRC

And 2 graduate students (Brian, Rich)

Backstory

(Briefly)

Not your typical research project

Sakae wanted to apply aluminum casting and plate designs to the nuclear market

Dr. Marc Skinner (former Executive Officer IF) approached Sakae through REDI and our State Senator Kelly Anthon

Marc introduced the Sakae team to Prof. Christensen at a reception in Blackfoot that I apparently wasn't invited to in 2017

Rich drew up a concept on a napkin, as he does, for a used fuel cooling cask (PWR) that could apply their casting technology

A few weeks later, I saw everyone walking around CAES, so I stuck my nose in, as I do, and got involved

Then we roped in Brian

What is unique about Sakae?

Casting technology is a vacuum process using sand molds (won 'green' awards)

Method of casting the aluminum and the cooling tubes allows for more efficient heat transfer

Process costs less overall

The Idaho Global Entrepreneurial Mission awards funds for products to go to market

We submitted an application in May 2017 - 2 years to design, fabricate, test prototype (Not a typical proposal)

We didn't get it but worked on the feedback over the summer to submit in September 2017

We were invited to the big city in Boise to present the proposal to the Council

Interesting to be reviewed in real time

After fielding their questions, they settled on a year of funding to model, design, and work on a market plan


株式会社 栄鋳造所
SAKAE CASTING TEL:042-651-9790

What is the motivation for the project?

Assume everyone knows what used fuel is and what a pool is

We argue that there are some used fuel pools filling up

Assemblies need several years cooling before transfer to standard dry casks

Understand that some are transferred sooner - not necessarily internationally

Design a cask that could serve as an intermediate option between pool and dry storage

Intended for onsite storage - not a dual purpose cask - storage only

I did a ton of market research - Highlights

United States
Should be well known enough
63% capacity (2017)
'Healthy' dry cask program

South Korea
70% capacity over 4 sites (2014)
Reracking and moving fuel from old sites to new

Taiwan
97% capacity (2015)
Restart of NPP denied by federal government due to lack of storage
Local government rejected dry cask plan

Japan
55% capacity (2013) - Rokkasho almost filled (2018)
Dry casks in use but expansion requires local government approval
Combined wet and dry capacity at 71% (2018)

France
Most fuel stored at La Hague - onsite storage short
Plans for 8000 MTHM centralized storage

UK
Only 1 PWR
Dry cask construction started in 2016 - fuel loading in 2017 Could not find any % capacities

Germany
Well known enough here - phasing out NPPs
Dry cask storage extensive - 2 decades
Could not find any % capacities

Belgium
Similar to Germany - phasing out NPPs
Some dry cask storage
Empty pools at sites of shutdown NPPs and new pool constructed on active site
Could not find any % capacities

Basically ran out of useful information at this point

Did not include Finland and Sweden

What are the major takeaways from this part?

Turns out hard numbers on used fuel pool capacities were really hard to find

Active NPP nations that are once through and not phasing out

For the most part, Europe doesn't seem to be a potential market

Most Asian countries lack robust dry storage

United States could go either way

Ideally would like to talk to US energy companies

We have several functional requirements

Effective heat removal - Rich+Winfred

Materials optimization - Brian+Sam
About 12% solid solution with but pouring problems

Shielding - How thick will the cask be? How much do we need? - Coming up
Occupational safety - dose rate less than

Licensing - What are the right regulations? What is needed for licensing? - Coming up

Market penetration - Who wants it? - Sakae - Next

Realistically, the cask probably will only be effective for certain fuel types

Sakae attended several exhibitions worldwide to engage companies

This was a discussion we had with the IGEM council

World Nuclear Exhibition in Paris (June 2018)

Talked to...
Doosan, KEPCO, NESS (South Korea)
Hitachi GE (Japan)
EDF Energy (UK)
Orano TN (USA)

Consensus was that there is interest but want to see specific design data, cost analysis, and safety assessment

Let's move on to the technical portion of the show

I used ORIGEN for burnup and depletion

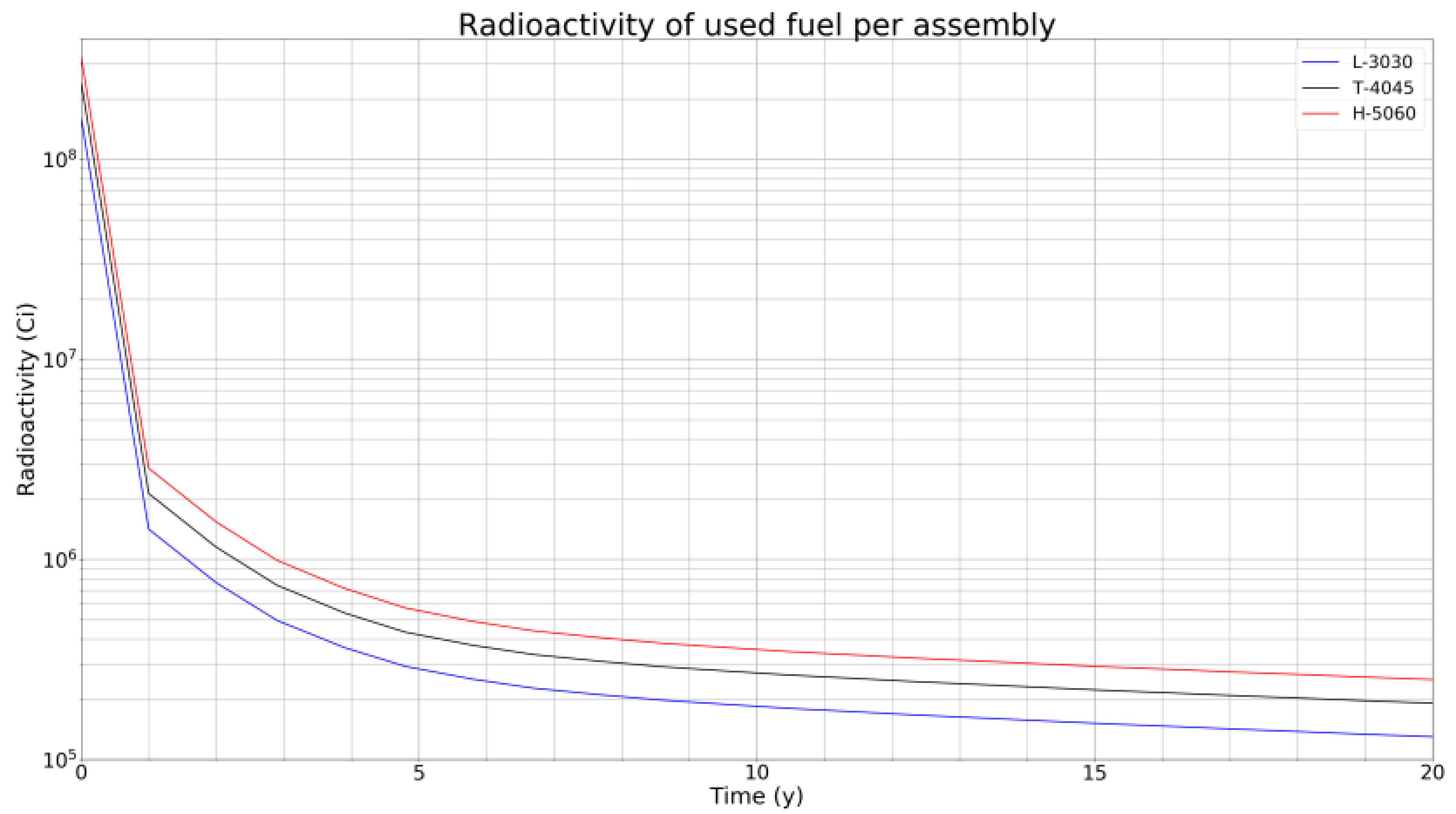
Thanks to Steve Skutnik for help

Divided the cases in to low burnup, typical burnup, high burnup

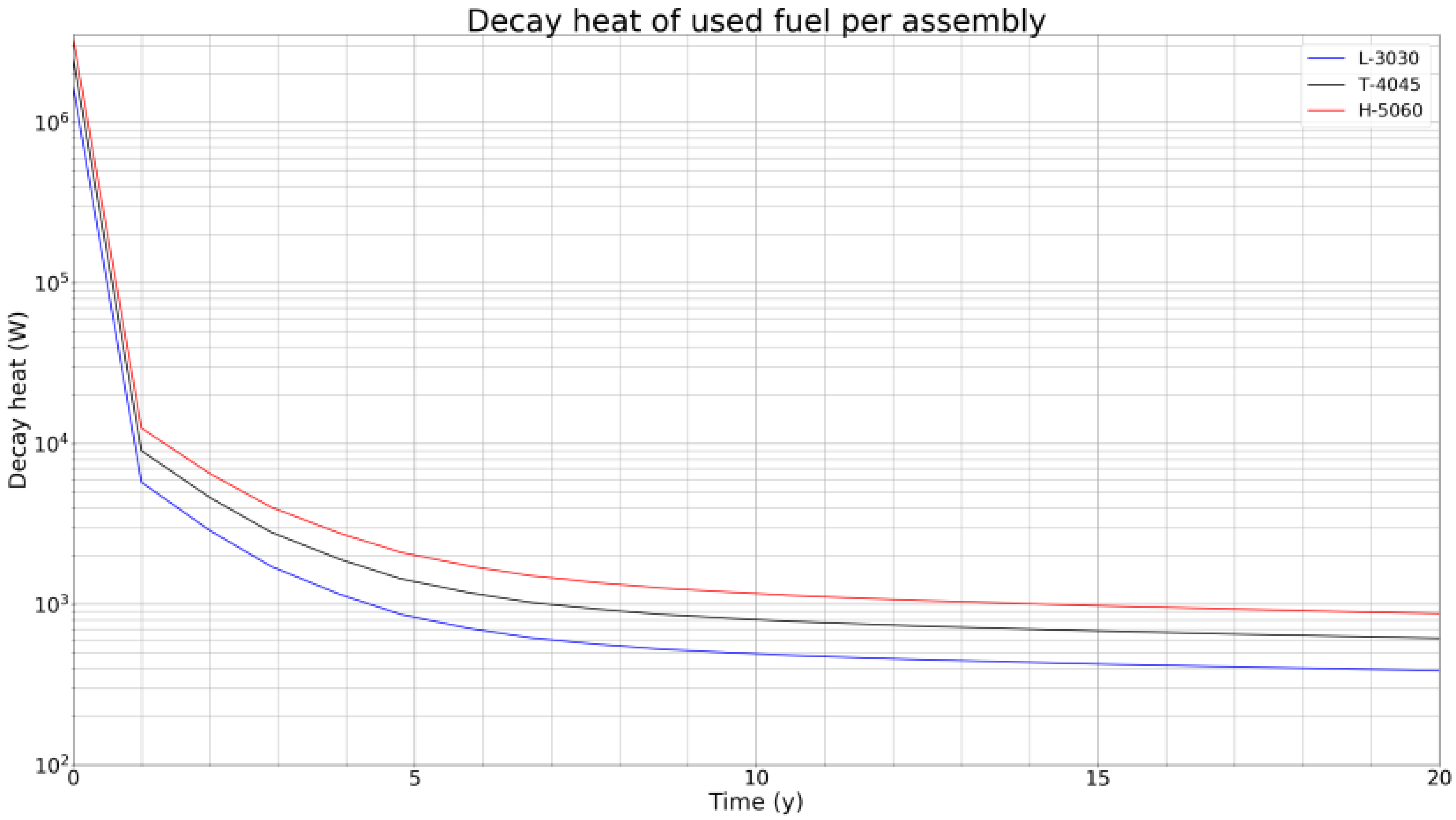
(Read - N-XXYY - X.X% and YY GWD/MTU)

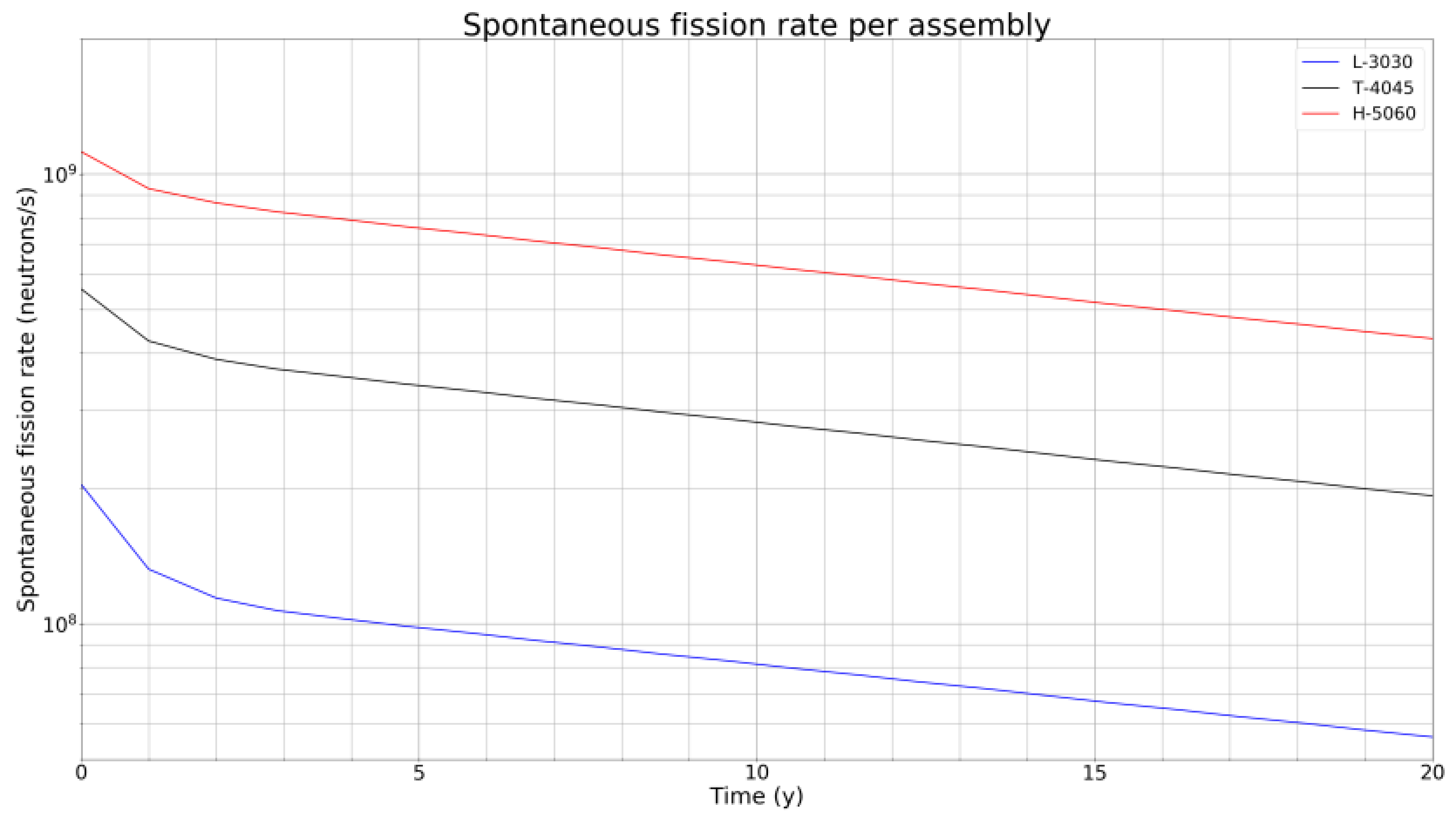
L-3030,L-3530,L-3033,L-3133,L-3233,L-3533,L-3240,L-3540,L-4040
T-4045,T-4545,T-5045,T-4050,T-4250,T-42550,T-4550,T-5050
H-4555,H-5055,H-4560,**H-5060**

Westinghouse 17x17 PWR
515 day cycle length and pool cooling (decay) from discharge out to 20 years



Radioactivity of used fuel per assembly
L-3030
T-4045
H-5060
Radioactivity (Ci)
10^8
10^7
10^6
10^5
0
5
10
15
20
Time (y)


Decay heat of used fuel per assembly
L-3030
T-4045
H-5060
Decay heat (W)
10^6
10^5
10^4
10^3
10^2
0
5
10
15
20
Time (y)


Spontaneous fission rate per assembly
L-3030
T-4045
H-5060
Spontaneous fission rate (neutrons/s)
10^9
10^8
0
5
10
15
20
Time (y)

Cask design with MCNP

(oh no)

What's the plan?

I decided that the cask probably would only be useful for older fuel (20 y)

I wanted to start with a neutron shielding model

Cm-244 shown in ORIGEN simulations to be dominant emitter across the board (SDEF)

Plate thickness - 1.5, 3, 6, 12, 18, 30 cm

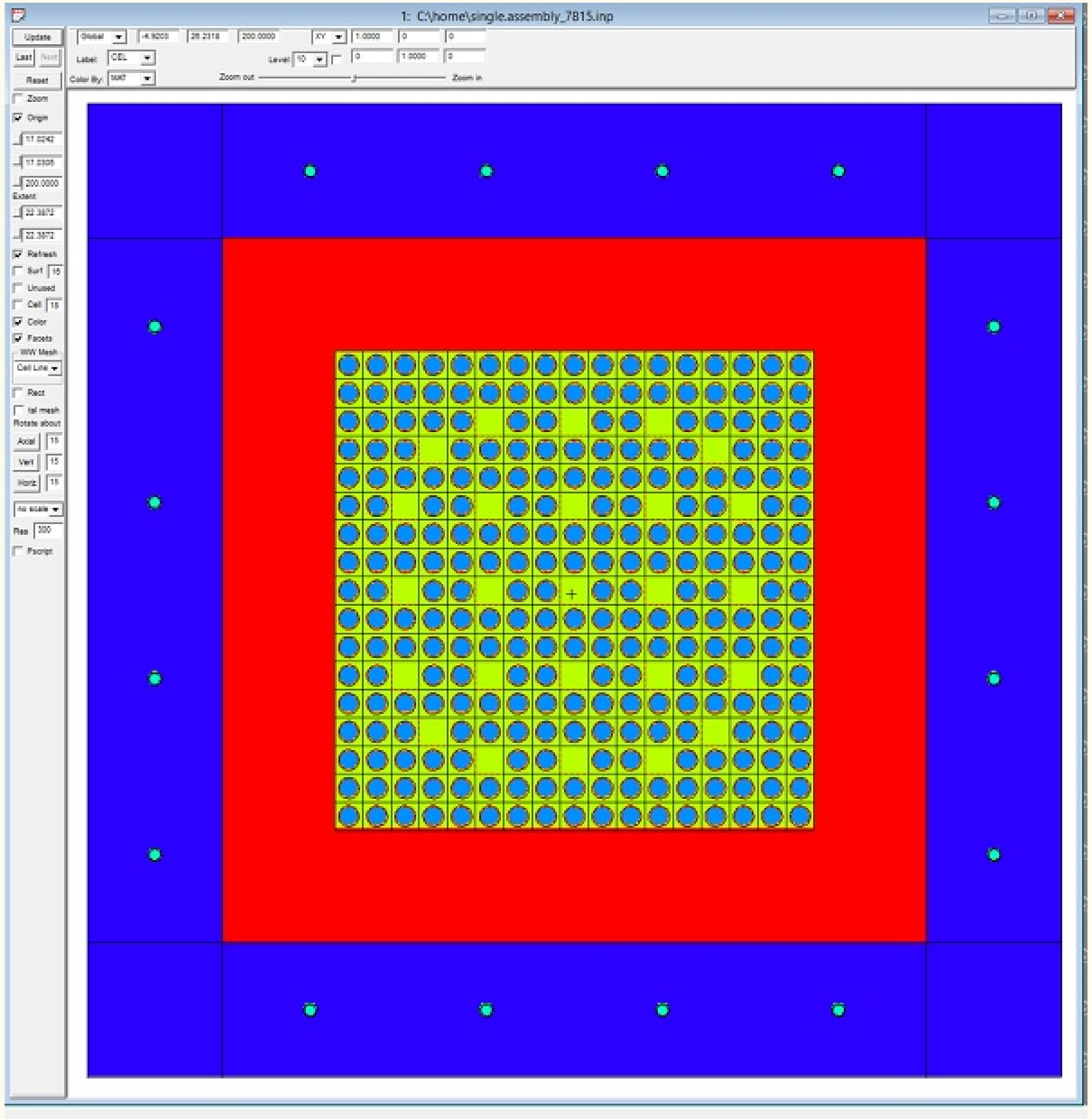
- 10, 30, 50, 70, 90 wt% in Al per plate thickness

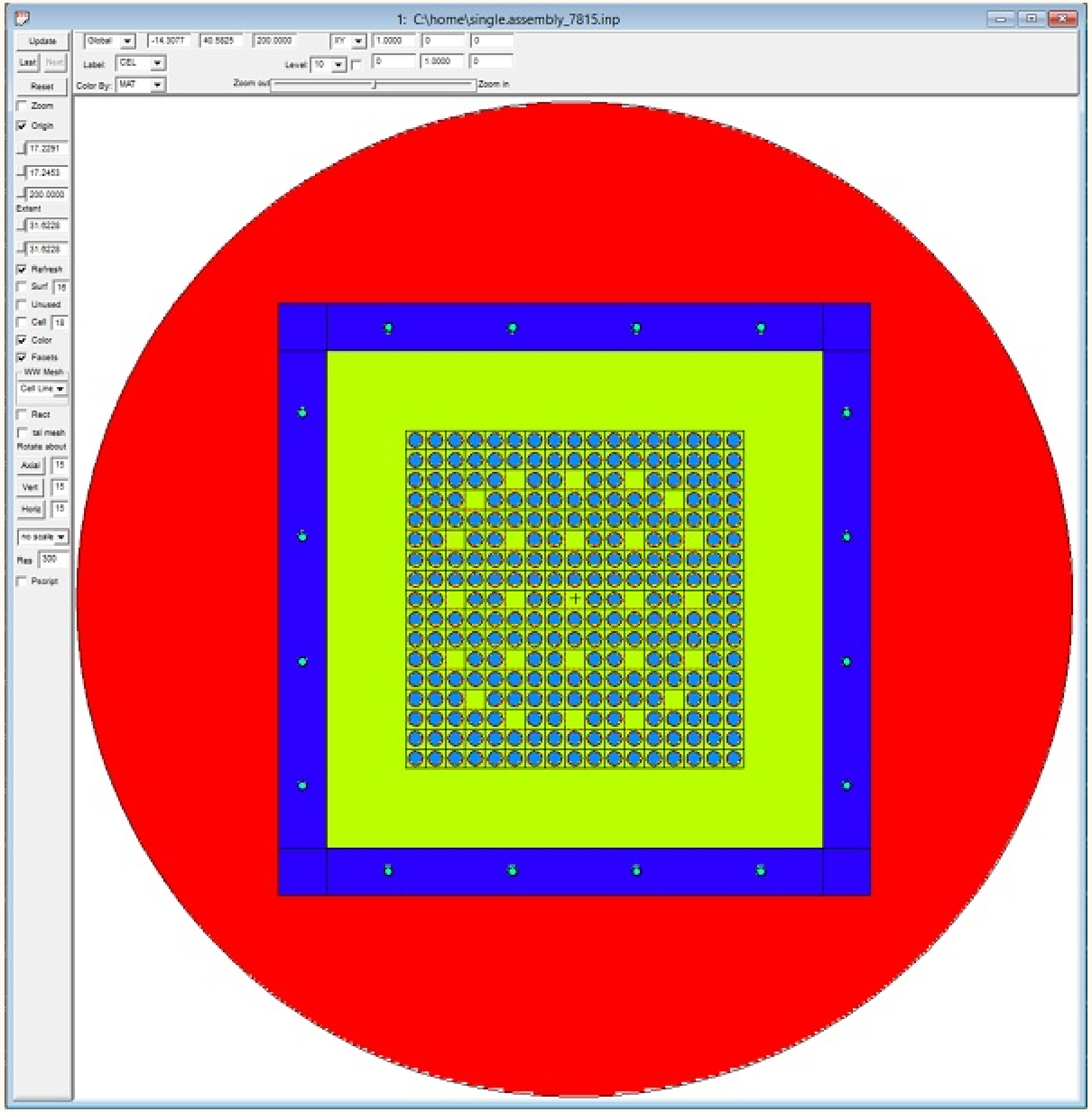
loading in - 5, 10, 25, 50, 75 wt%

For each enrichment-burnup

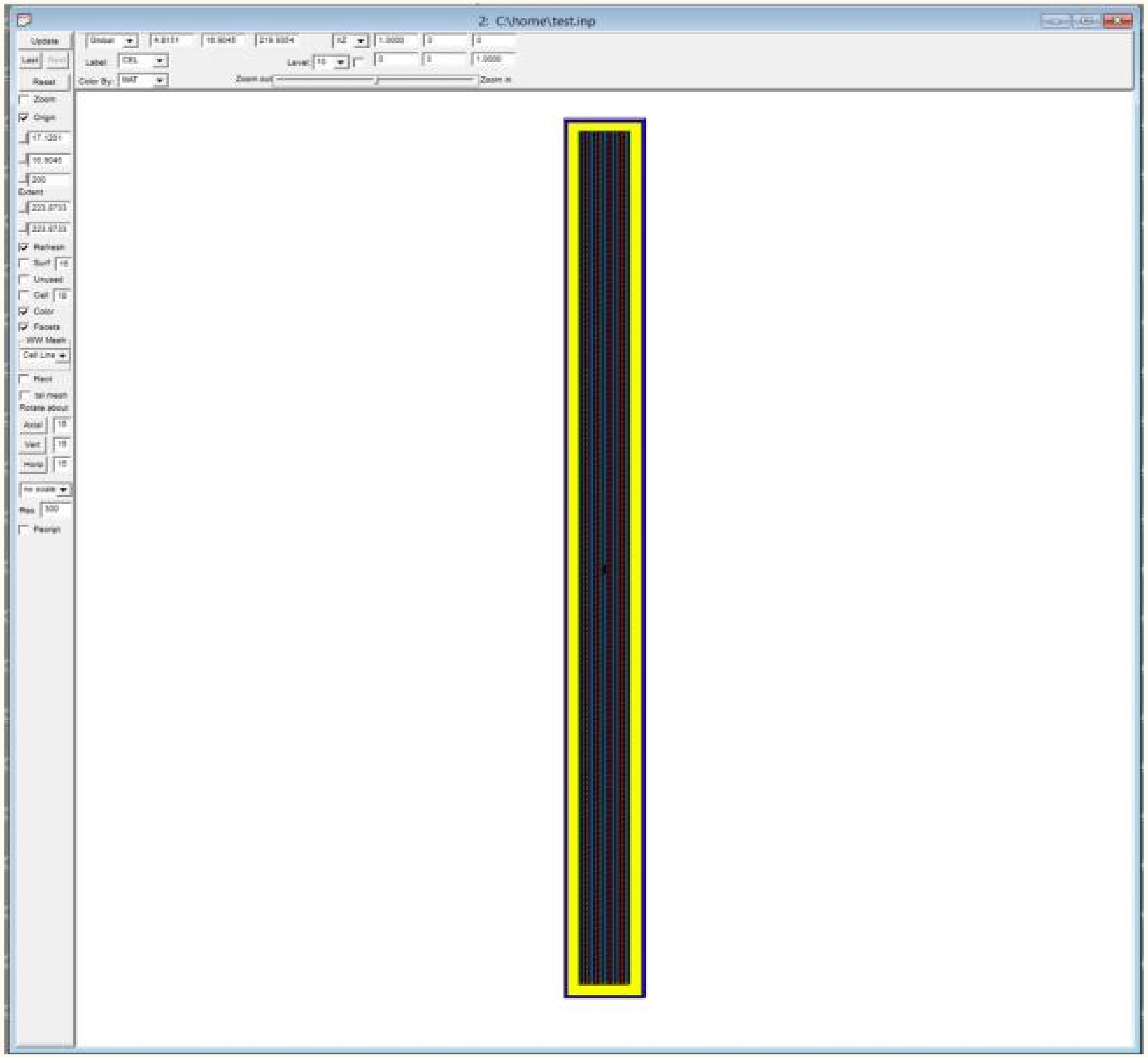
Then a second set of simulations emplaced in concrete - 3, 5, 10, 15, 20 cm

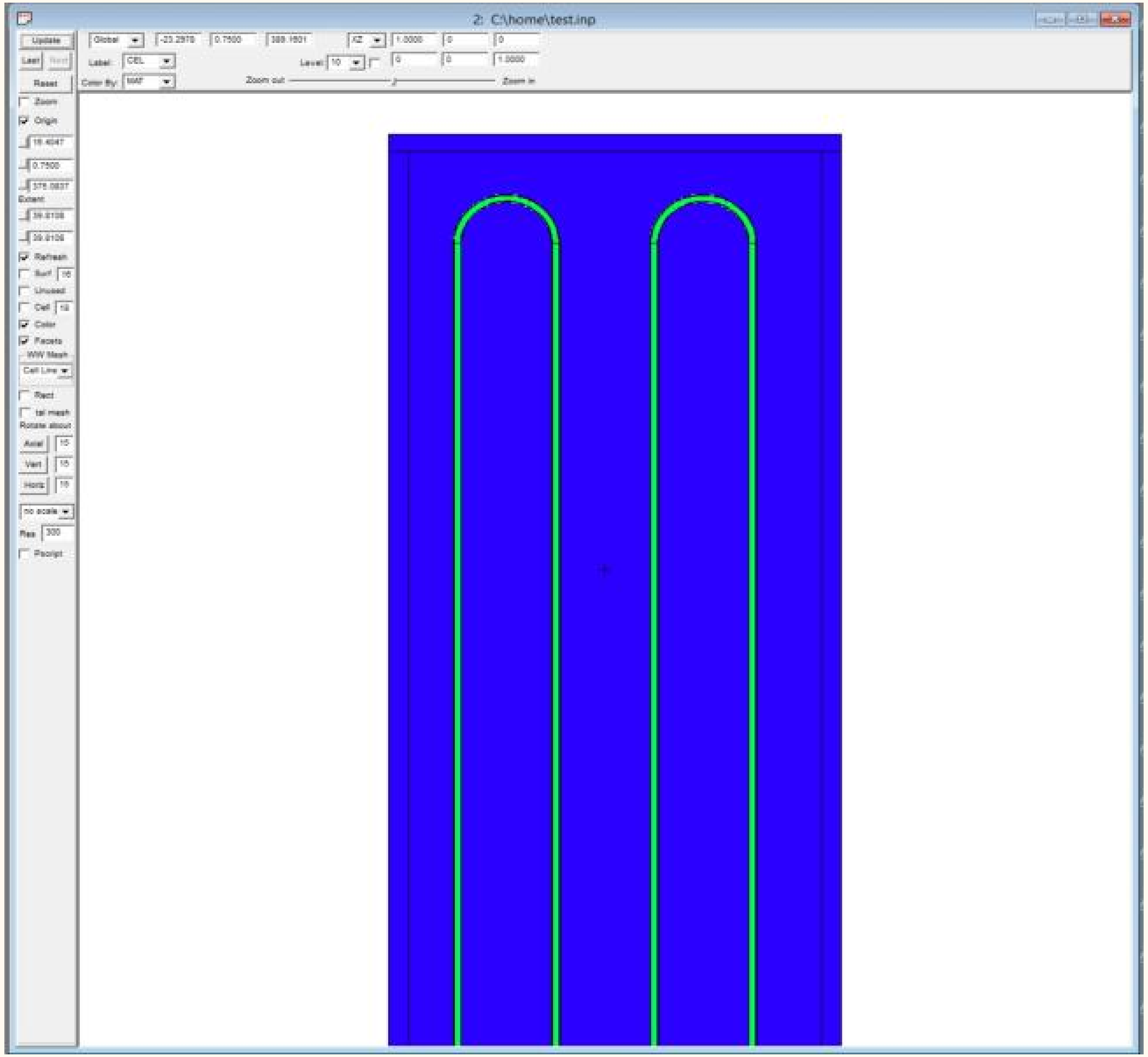
VISED views


1: C:\home\single.assembly_7815.inp


1: C:\home\single.assembly_7815.inp

#FancyMCNP


2: C:\home\test.inp


2: C:\home\test.inp

More MCNP modeling notes for your interest

Backfill - air, water, helium, borosilicate glass

Lattice card 17x17 unit cells - 269 rods - pitch 12.54 mm

Material card taken from ORIGEN output with 1E-08 wt% cutoff

MCNP output notes for your interest

Standard defaults for dose card

SDEF card - 5 source points per rod (POS)

ERG = Spontaneous Cm fission energy distribution

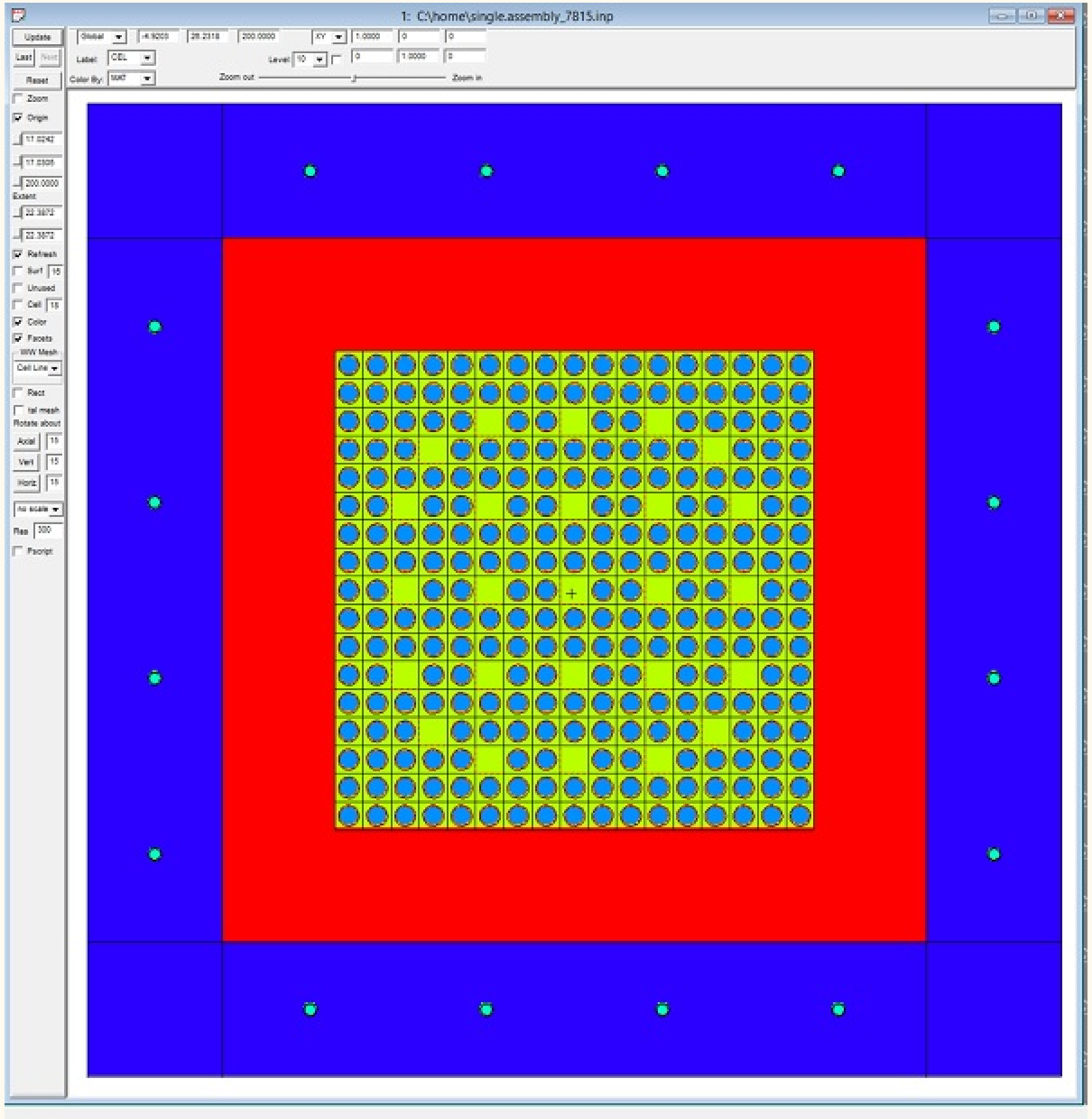
F2 tally for outward normal on each plate

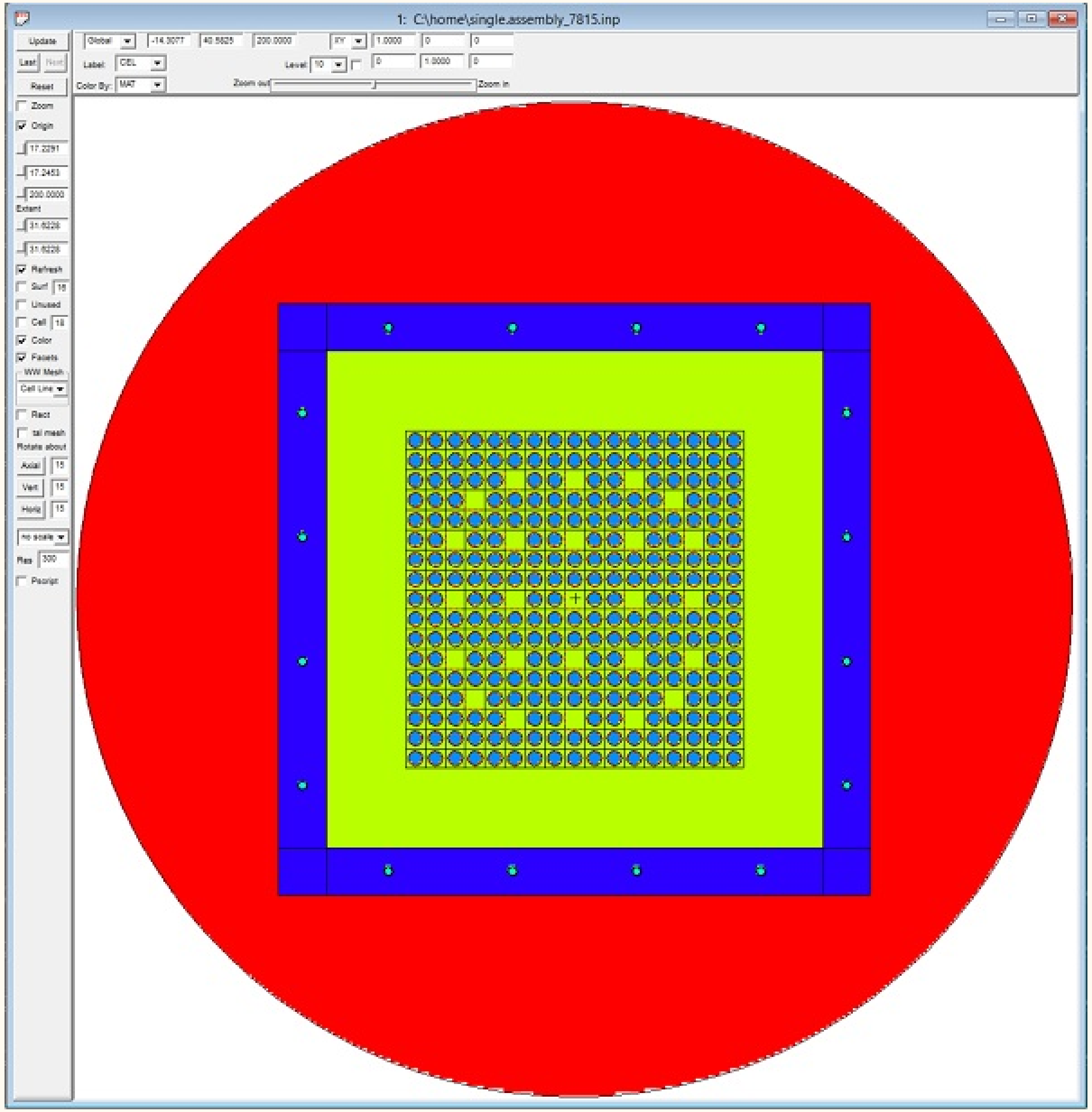
NPS 2E6 (bare) and 3E6 (container) passed all tests

Equal dose rates off plates - isotropic

Results

(so many pretty pretty graphs - how to choose?)


1: C:\home\single.assembly_7815.inp


1: C:\home\single.assembly_7815.inp

How I choose

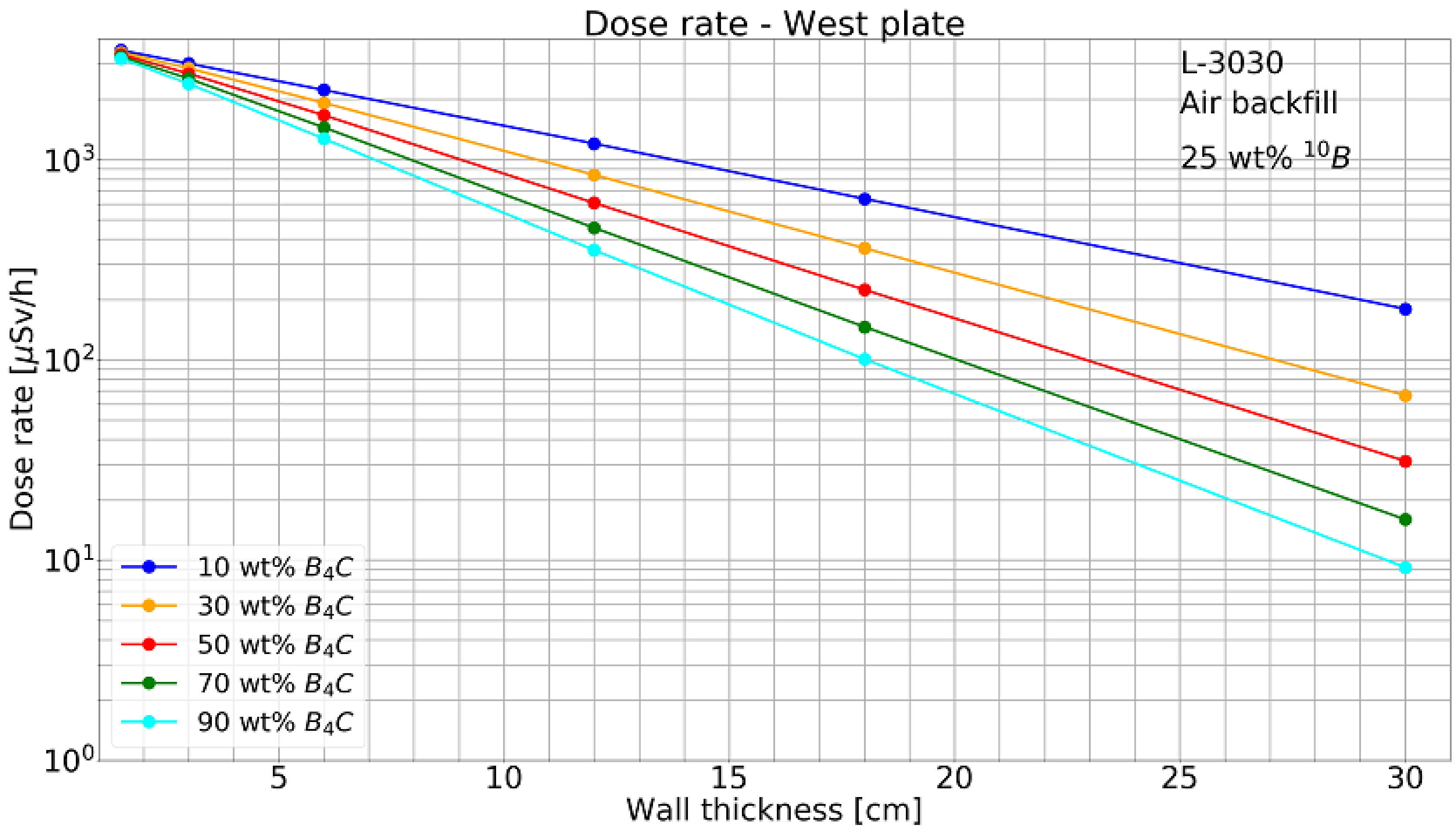
Helium and air backfill results basically the same

Haven't gotten to glass or T-4045 yet (HPC has been down almost month)

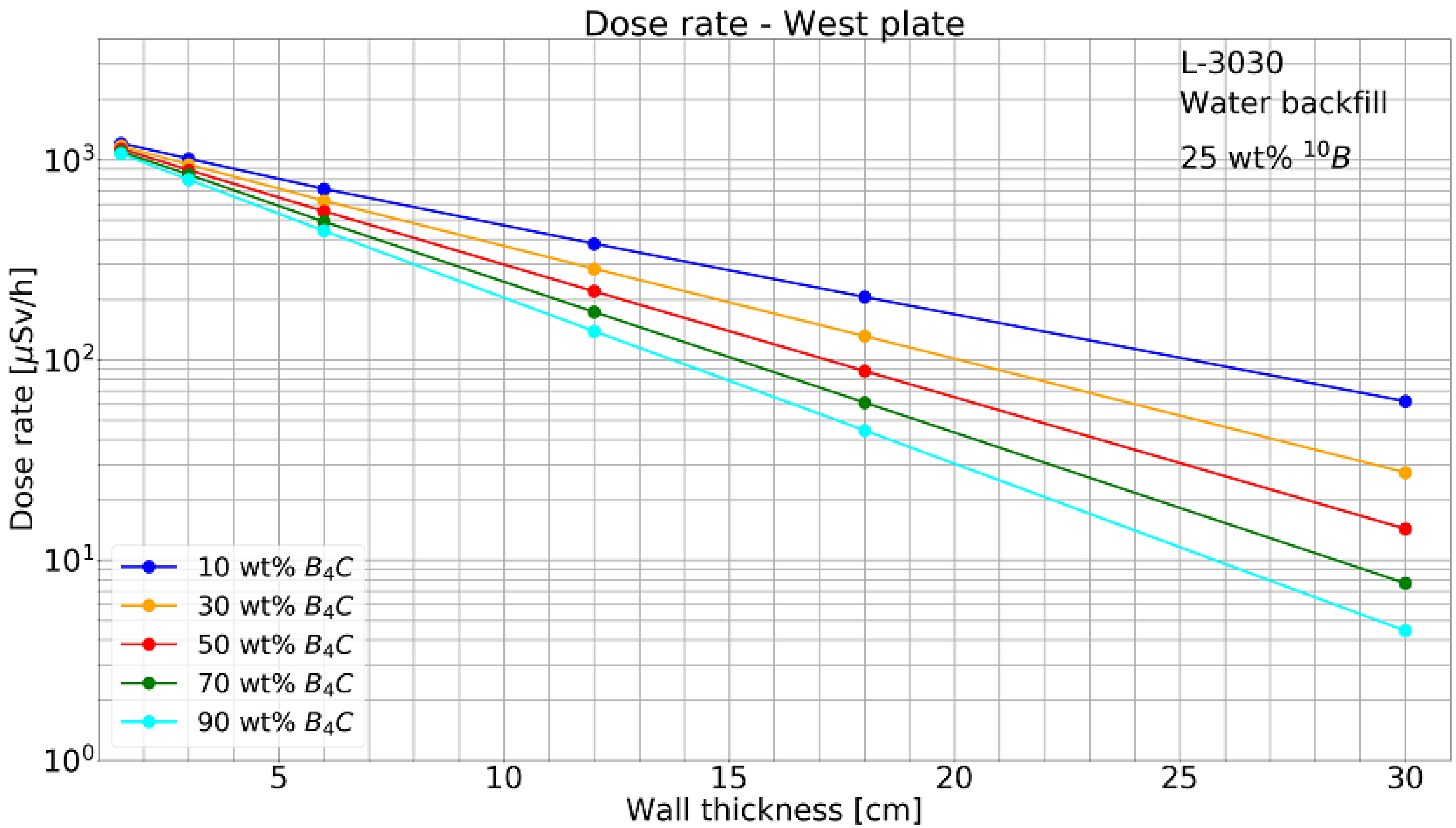
Didn't know about the 12 wt%   until 2 weeks ago

Showing results for 25 wt%

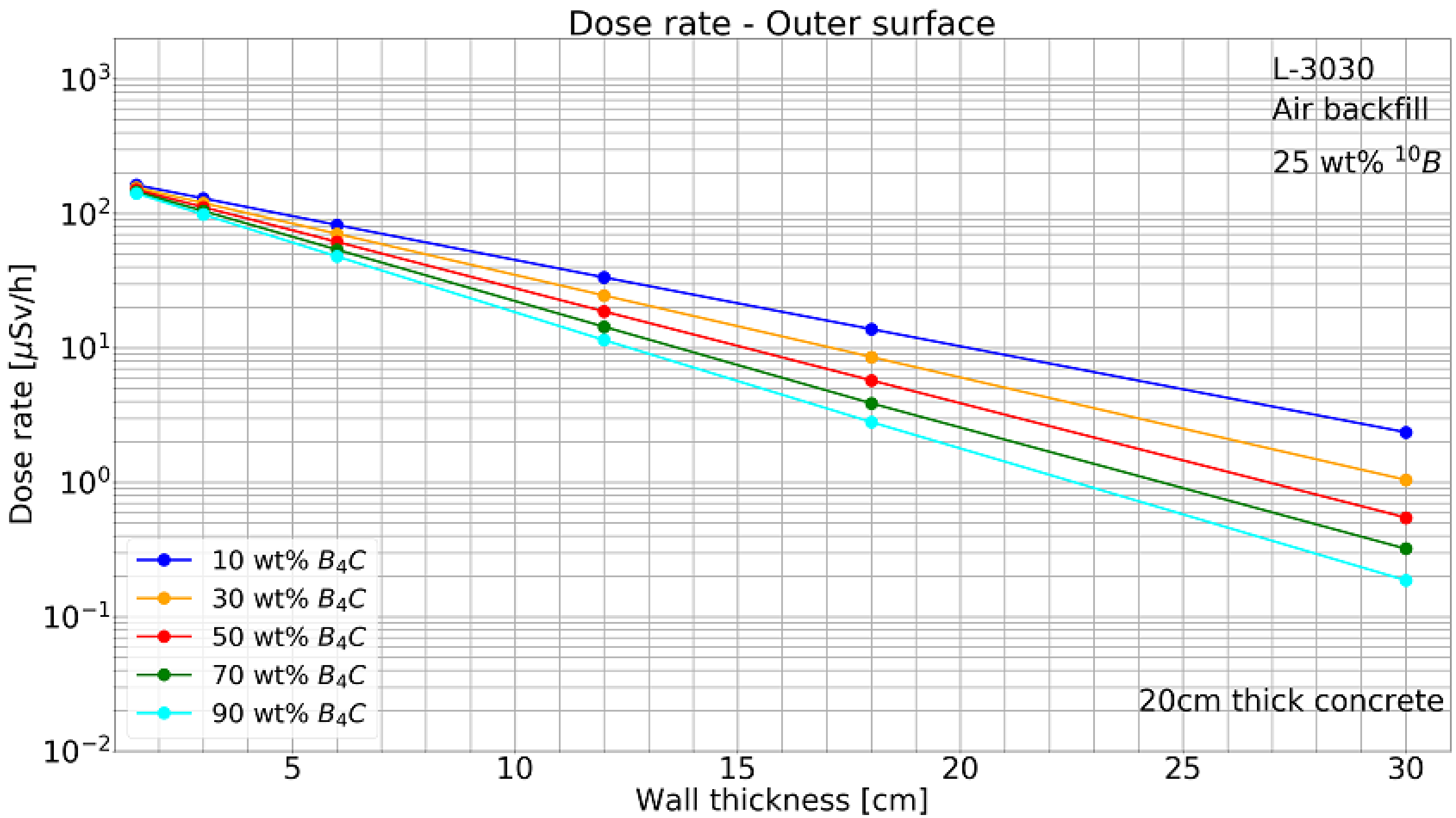
Looking for dose rate below

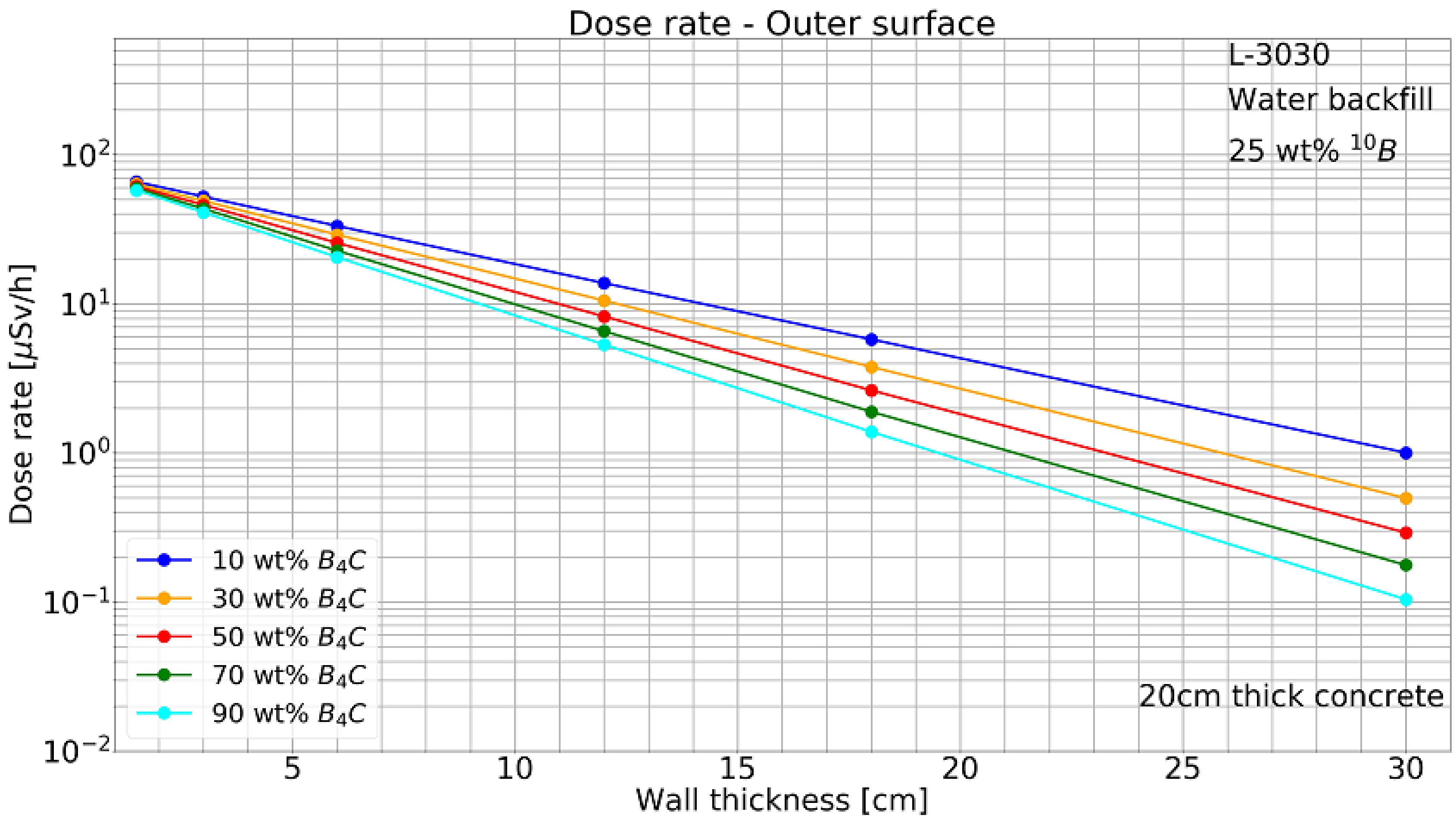


Dose rate - West plate
L-3030
Air backfill
25 wt% ^{10}B
Dose rate [μSv/h]
10^0
10^1
10^2
10^3
5
10
15
20
25
30
Wall thickness [cm]
10 wt% B_4C
30 wt% B_4C
50 wt% B_4C
70 wt% B_4C
90 wt% B_4C

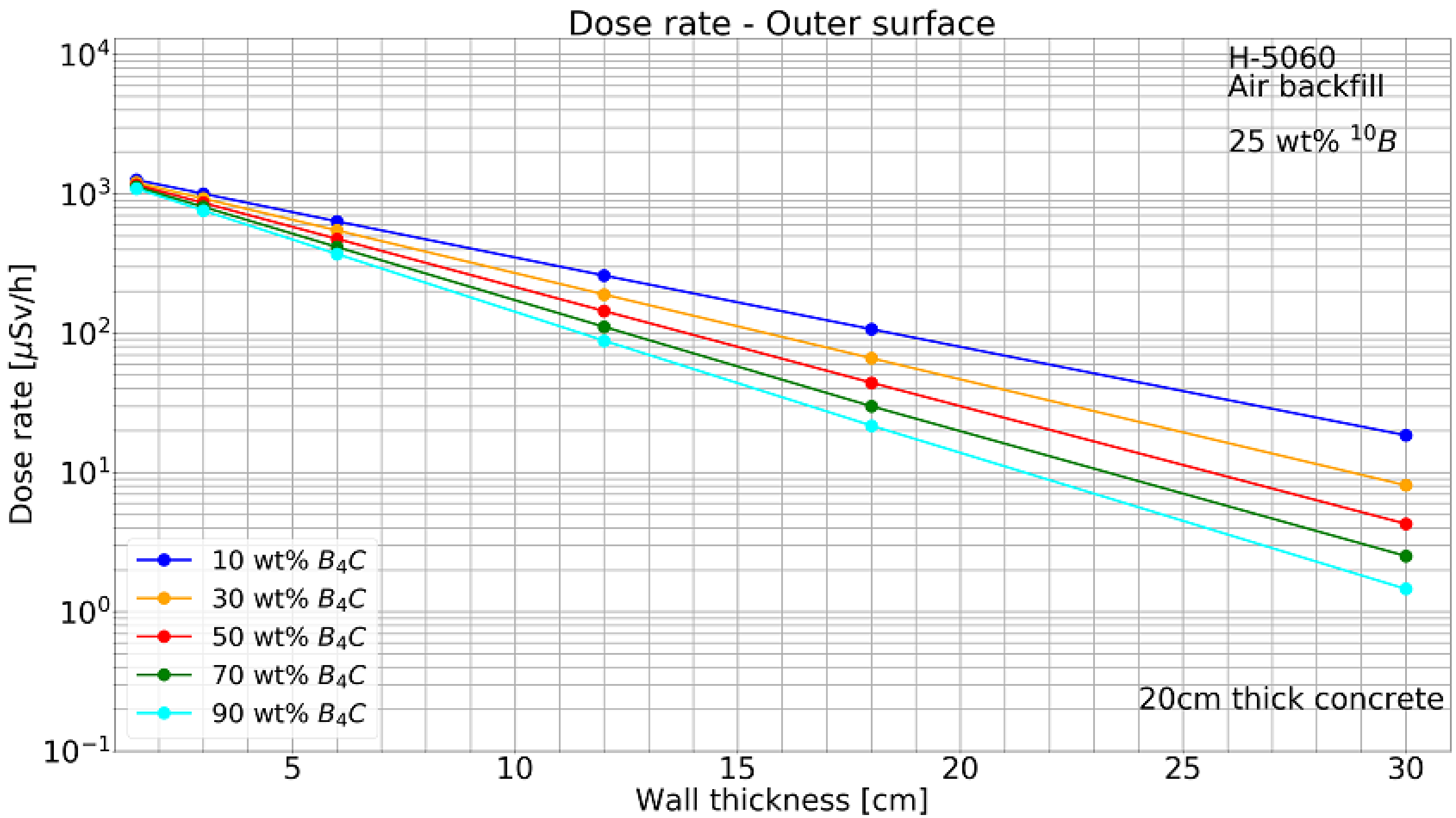


Dose rate - West plate
L-3030
Water backfill
25 wt% ^{10}B
Dose rate [μSv/h]
Wall thickness [cm]
10^0
10^1
10^2
10^3
5
10
15
20
25
30
10 wt% B_4C
30 wt% B_4C
50 wt% B_4C
70 wt% B_4C
90 wt% B_4C

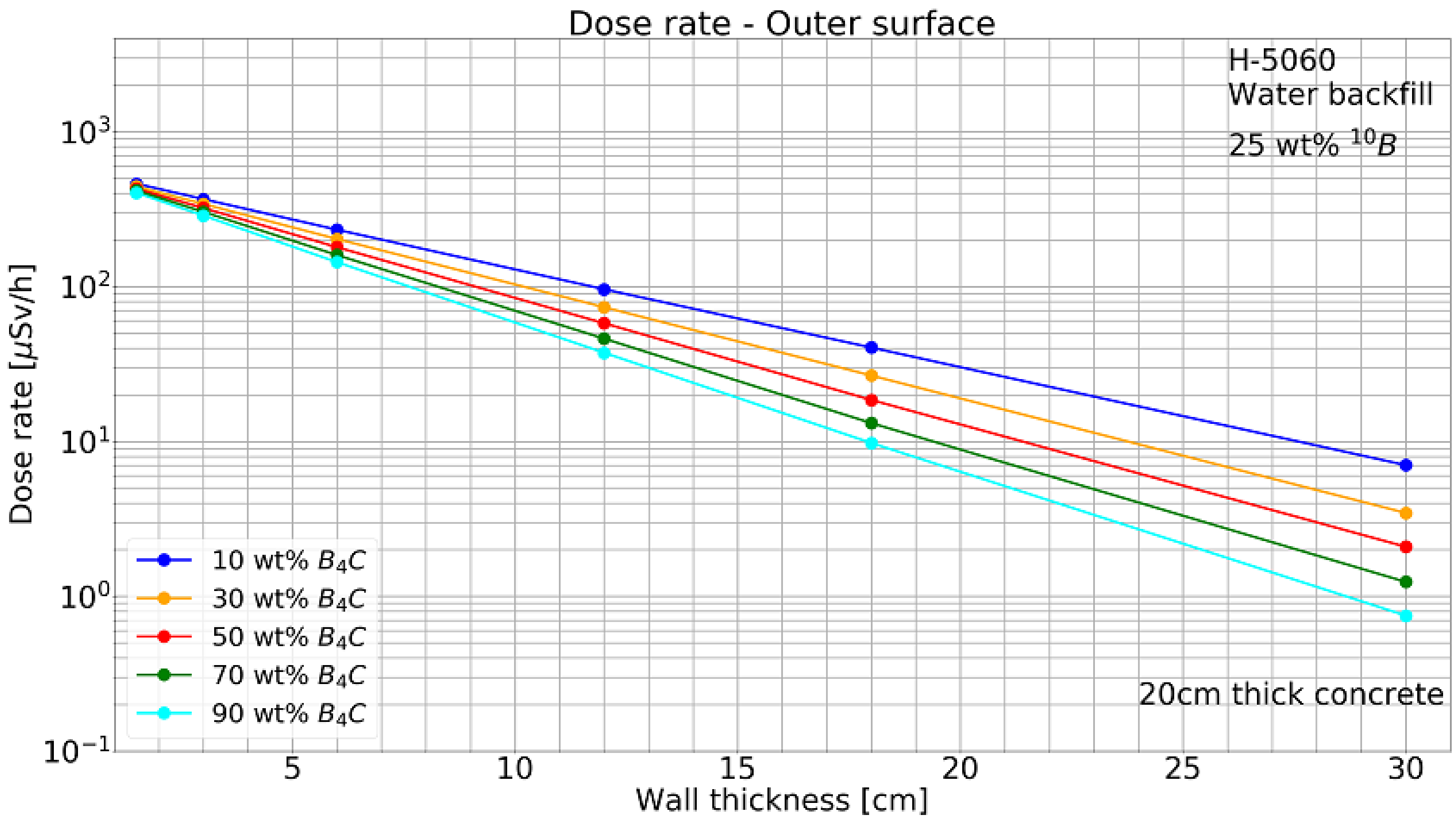

Dose rate - Outer surface
L-3030
Air backfill
25 wt% ^{10}B
20cm thick concrete
10 wt% B_4C
30 wt% B_4C
50 wt% B_4C
70 wt% B_4C
90 wt% B_4C
Dose rate [μSv/h]
Wall thickness [cm]
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
5
10
15
20
25
30



Dose rate - Outer surface
L-3030
Water backfill
25 wt% ^{10}B
20cm thick concrete
10 wt% B_4C
30 wt% B_4C
50 wt% B_4C
70 wt% B_4C
90 wt% B_4C
Dose rate [μSv/h]
Wall thickness [cm]
10^2
10^1
10^0
10^{-1}
10^{-2}
5
10
15
20
25
30



Dose rate - Outer surface
H-5060
Air backfill
25 wt% ^{10}B
20cm thick concrete
10 wt% B_4C
30 wt% B_4C
50 wt% B_4C
70 wt% B_4C
90 wt% B_4C
Dose rate [μSv/h]
Wall thickness [cm]
10^4
10^3
10^2
10^1
10^0
10^{-1}
5
10
15
20
25
30



Dose rate - Outer surface
H-5060
Water backfill
25 wt% ^{10}B
Dose rate [μSv/h]
10^3
10^2
10^1
10^0
10^{-1}
5
10
15
20
25
30
Wall thickness [cm]
10 wt% B_4C
30 wt% B_4C
50 wt% B_4C
70 wt% B_4C
90 wt% B_4C
20cm thick concrete

What do the results mean for design?

Greater than 25 wt%   might be cost prohibitive

Plate thickness greater than 20 cm might be too much to actually cast

Use of water backfill may be criticality risk if there are multiple casks

12 wt%   constraint may be difficult to overcome

High burnup fuel may not be feasible

Brief comments on regulatory compliance

I suggested NRC certification to enhance marketability

Currently 4 companies have obtained compliance each with different models

NUHOMS, MAGNASTOR, HI-STAR, HI-STORM (51 total)

10CFR72 is the relevant regulation

In short, the regulation is highly performance based

Demonstrate subcriticality, heat removal, occupational safety, etc.

Much of 10CFR72 is devoted to QA, which we can't do at this time

Important - 72.236f stipulates passive cooling which will need to be addressed

What's next?

Largely out of time

Need to meet with all to determine actual casting capabilities and design review

Glass backfill may yield more promising results

Determine significance of neutron activation of aluminum

Prepare second year application