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Operational Impacts of High Reactivity Targets or the perils of relearning old lessons in a new regulatory environment.

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Research Problem / Opportunity

- The United States currently faces a shortage of medical isotopes for both clinical use and research and development.
- Funding is available!
- ^{64}Cu and ^{67}Cu are two key isotopes identified as being in short supply; their emissions and their moderate half-lives make them effective for diagnosis and treatment.

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Operations Problem / Opportunity

- Experimenters are unfamiliar with experiment or techniques – its new to them
- High Reactivity, Heat Generation, High Radiation, "New" Materials
- Research/Experiment – hypothesize, trial …. error
- Non-routine experiment becomes routine
- Time pressure, holding up research at RESEARCH reactor
- Oversight and conservatism - when to say **NO**

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Research Isotopes of Interest

^{64}Cu	^{67}Cu
$t_{(½)}$ = 12.7 hours	$t_{(½)}$ = 61.8 hours
β^+ ~278 keV (17.9%) EC (43.1%) β^- ~191 keV (39.0%)	β^- ~141 keV (100%) γ 184.6 keV (48.7%) 93.3 keV (16.1%) 91.3 keV (7.0%)
PET scans and tracking metabolic disorders	Cancer treatment and medical imaging

Research Methods of Production

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Method	Reactions	(+) Advantages	(-) Disadvantages
Charged particles	$^{64}_{28}Ni + ^{1}_{1}p \rightarrow ^{64}_{29}Cu + ^{1}_{0}n$ $^{64}_{28}Ni + ^{4}_{2}\alpha \rightarrow ^{67}_{29}Cu + ^{1}_{1}p$	• Target separations • High cross sections • High specific activity	• Limited accelerator time • Cost of ^{64}Ni is high and quantities are limited

Simple $(n_{thermal},\gamma)$	$^{63}_{29}Cu + ^{1}_{0}n \rightarrow ^{64}_{29}Cu$
	$^{66}_{29}Cu + ^{1}_{0}n \rightarrow ^{67}_{29}Cu$
		• Readily abundant thermal neutrons
		• High cross sections
			• No chemical separation:
			  • Isotopic dilution
			  • Low specific activity

Reactor production	$^{64}_{30}Zn + ^{1}_{0}n \rightarrow ^{64}_{29}Cu + ^{1}_{1}p$ $^{67}_{30}Zn + ^{1}_{0}n \rightarrow ^{67}_{29}Cu + ^{1}_{1}p$	• Target separations • High specific activity • Use of large targets • Available reactors	• Low cross sections • Lower n_{fast} flux

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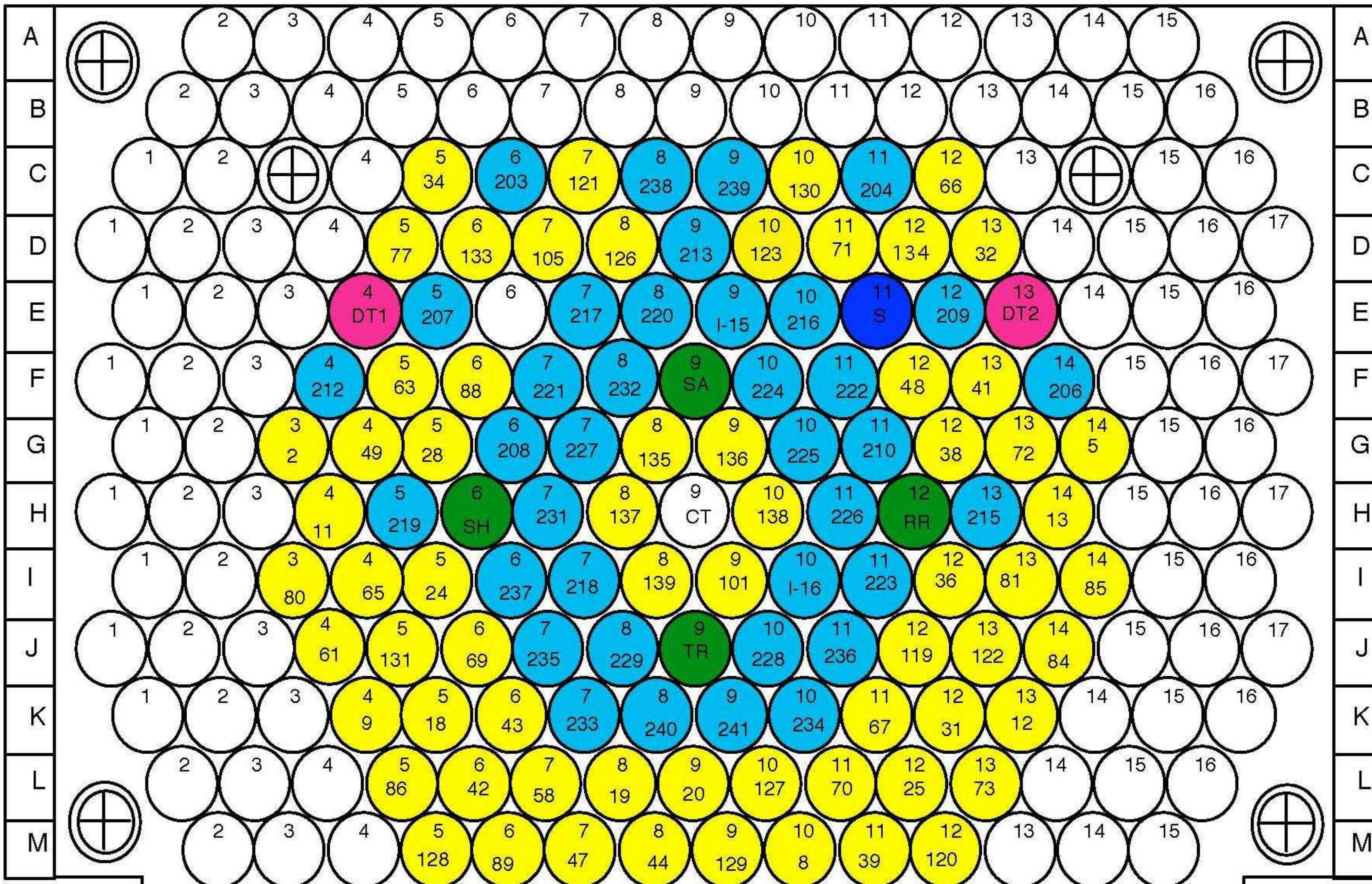
Core Loading 55



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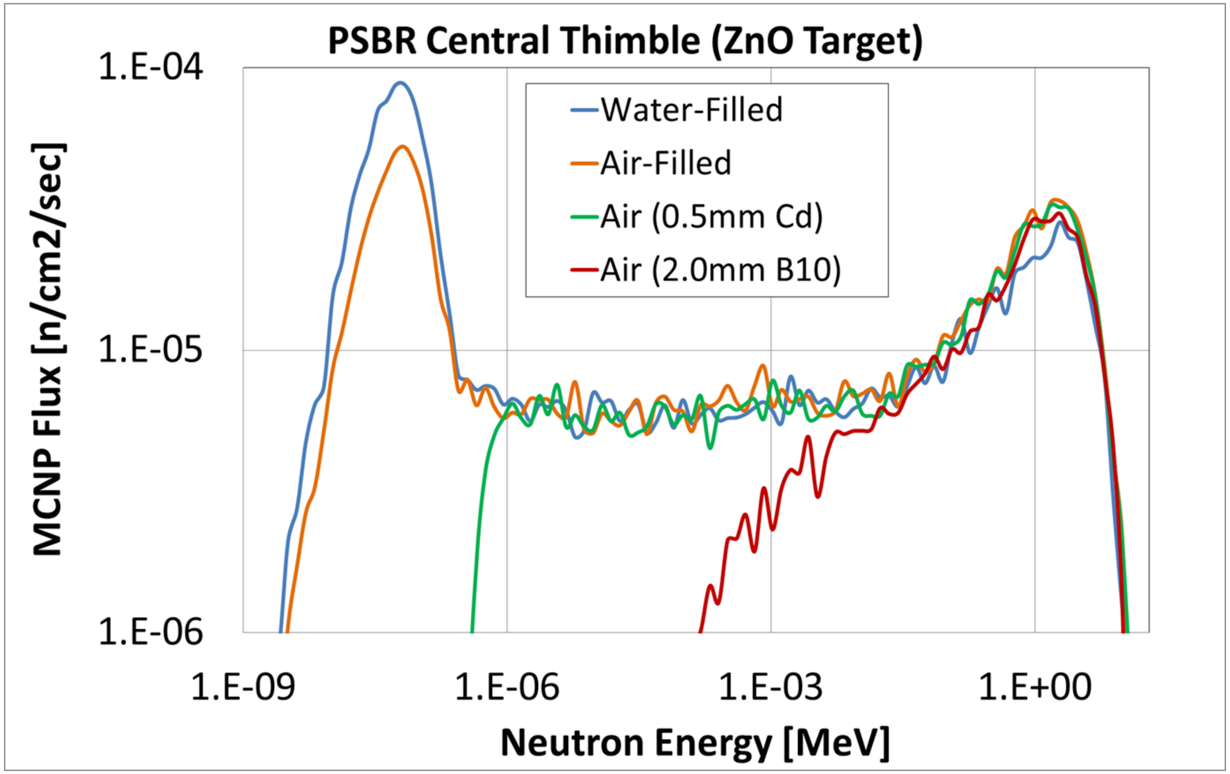
Irradiation Facility Design

Condition	Thermal Flux 0-1 eV	Fast Flux 1-20 MeV
Water-filled	100%	100%
Air (Bare target)	80%	126%
Air (0.5 mm Cd shield)	42%	123%
Air (2.0 mm ^{10}B shield)	24%	113%



Shielded Irradiation Capsules

Rev.1
$1.20

Rev.2
$1.49

Operations had concerns over reactivity of holders

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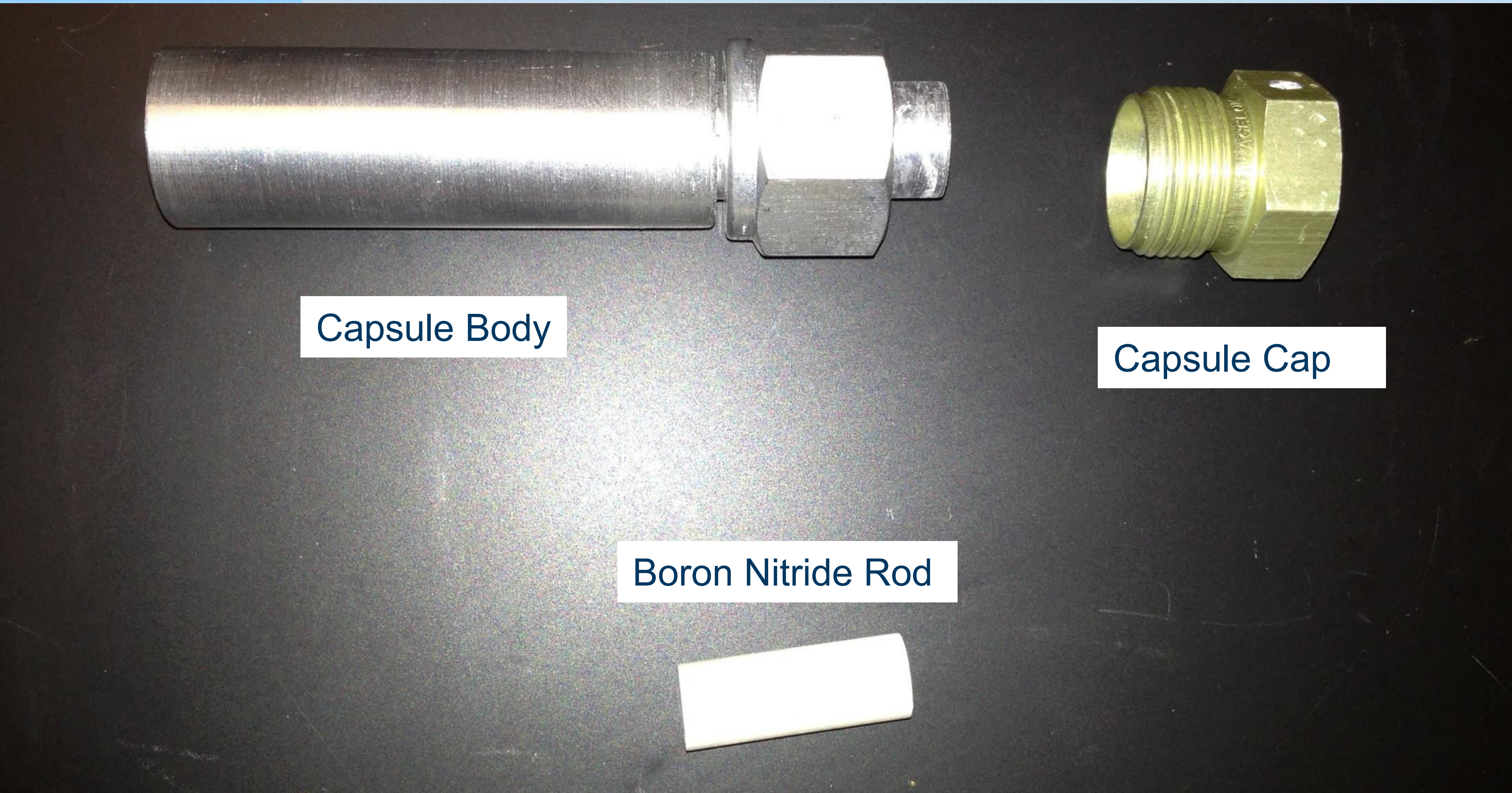
Irradiation Capsule (Rev. 3 $.80)



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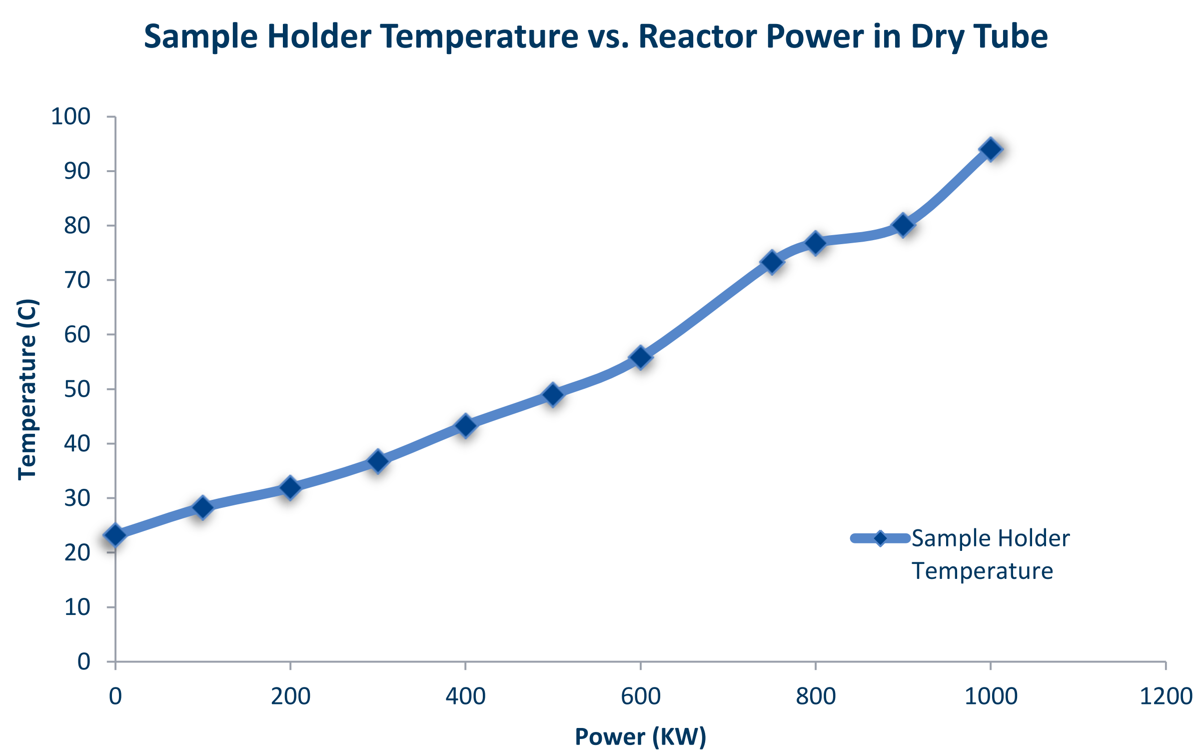
Review concerns
tests and predictions

Review Concern – Heat Production --- Swelling

		MCNP F6 tally results		
Rev. 2	**mass (g)**	**mev/g/source particle**	**MeV/s**	**Watts**
sides	66.9	1.37E-04	7.15E+14	114.5
bottom	22.5	1.33E-04	2.34E+14	37.5
			Total	**152**
Rev. 3				
sides	35.9	1.89E-04	5.3E+14	85.1
bottom	14.0	2.03E-04	2.2E+14	35.4
			Total	**120**
Rev 4				
sides	26.2	1.89E-04	3.9E+14	62.0
bottom	3.31	3.02E-04	7.8E+13	12.5
plug	6.29	1.66E-04	8.1E+13	13.1
			Total	**88**

Review concerns
TESTS AND PREDICTIONS

Review Concern – Heat Production --- Swelling



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Reactivity Concerns Predictions and Checks

Design	MCNP	Measurement	Deviation
rev 1	-$1.36	-$1.20	13%
rev 2	-$1.53	-$1.49	3%
rev 3	-$0.79	-$0.80	-1%
rev 4	n/a	-$0.12	n/a

Flux maps OK with Conservative affect on Nuclear Instruments

Flux Runs

2 hour flux run in central thimble

- Lot of oversight, reactivity checks, no problem except
- Could not get the sample holder open Boron Nitrate plug sealed itself

- Couple days later another run with slight design change….. Same problem

Third time is a charm …. Now routine….?

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Operational Event High Power Scram - April 16

1415 ADO assumes RO watch to get sample going.

1501 Reactor @ 1 MW with sample in central thimble.

1520 Watch Team turnover to “new” staff SRO and student RO.

1650 RO/SRO discuss shutdown vs. pulling sample. Pulling low reactivity timed samples at low power is “routine”.

1701 Sampled pulled by SRO, High power scram (106% digital, 108% analog) Peak power 1.328MW Fuel Temp increase 1 degree C

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Operational Event Actions and causes

Immediate actions

- Reactor secured and tagged out
- Management notified
- Operational stand-down, critique and event review

Causes

- Mindset, group think, habit intrusion,
- Experiment authorization inadequacy,
- Experiment authorization procedure inadequacy

Follow-up actions

- Experiment authorization suspended, all others reviewed for adequacy/suspended
- Experiment authorization procedure under revision
- Operator training on prompt jump and safety analysis

Reportability Determination

All systems performed as designed, experiment in compliance with TS - *Initially determined not reportable*

Student SRO brought up concern with literal compliance

- For *Non-Pulse Mode Operation* TS 3.1.1.c. states *"The maximum power level shall be no greater than 1.1 MW (thermal)."*
- Basis is to protect Steady State decay heat assumptions and source term.

NRC position, report now, withdraw if not reportable.

Reported prior to the end of the next business day.

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TEST REACTOR EXCEEDED LICENSED POWER LIMIT DURING A SCRAM

The following information was excerpted from an email from the licensee:

On April 16, 2013 at 1701 EDT, the research test reactor automatically shutdown from 100% power (1 MW) due to a valid high power condition. The duty Senior Reactor Operator removed a timed irradiation sample from the core that added positive reactivity. Both the digital (non-safety system) and the analog safety system acted on the high power condition and initiated the shutdown. All systems functioned as designed. The short duration power transient reached a peak power of about 1.3 MW. There was no increase in radiation levels, personnel radiation exposure, or release of radiation from the facility. No emergency event entry criteria were met. The plant was placed in a secured condition and an event review investigation was conducted.

The event is (potentially) reportable in that the Maximum Power Level observed during the short duration (< 1 second) transient exceeded the steady state power limit for non-pulse mode operation as described in Technical Specification(TS) 3.1.1 Non-pulse mode operation sub-section b. The maximum power level shall be no greater than 1.1 MW (thermal).

The reactor was returned to routine service at approximately 1300 EDT on April 17, 2013.

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Thoughts, Questions,… Fallout

Operators are the last line of defense, we fail them every time we challenge them.

All our reviews, concerns, and plans did not prevent this event. They *knew* better, but had to learn again.

Experiments are trials and errors, there were two more minor events in this experiment series. We are trying to relearn a production method from years ago…

Questions? Feedback?

end

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ALARA
New Danger Tag

DANGER VERY HIGH

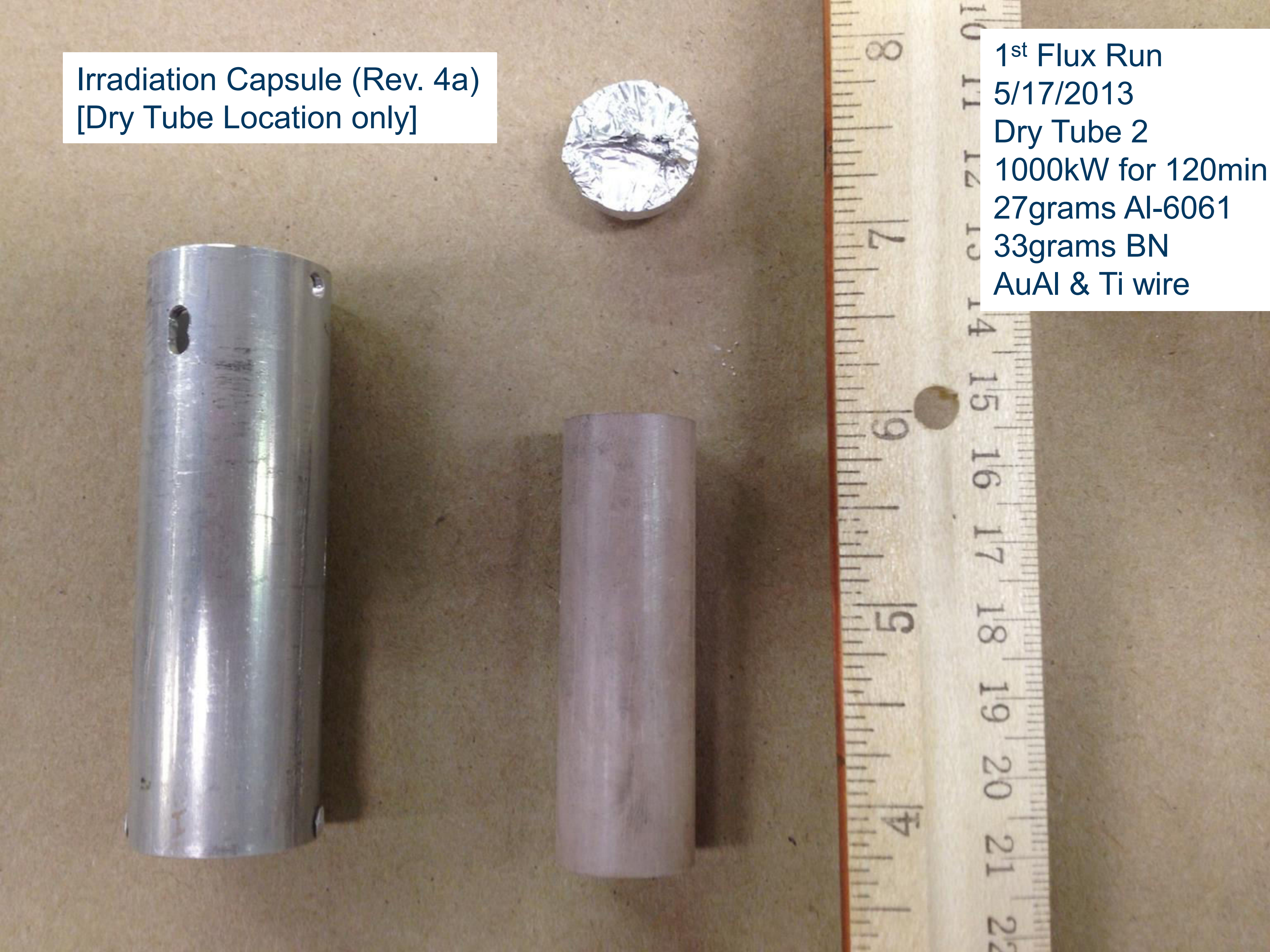
RADIATION SOURCE

DO NOT REMOVE

BEFORE:

_____5/10/2013_____

DATE	TIME	RADIATION LEVEL [R/HR]
5/8	12pm (t=0)	10,000
5/8	6pm (t=6)	1.250
5/9	12pm (t=24)	0.420
5/10	12pm (t=48)	0.150


Irradiation Capsule (Rev. 4a)
[Dry Tube Location only]
1st Flux Run
5/17/2013
Dry Tube 2
1000kW for 120min
27grams Al-6061
33grams BN
AuAl & Ti wire

Irradiation Capsule (Rev. 4b)
[Dry Tube Location only]

2nd Flux Run
5/24/2013
Dry Tube 1
1000kW for 6min.
14grams Al-6061
33grams BN
AuAl & Ti wire

Irradiation Capsule (Rev. 4a)
[Dry Tube Location only]

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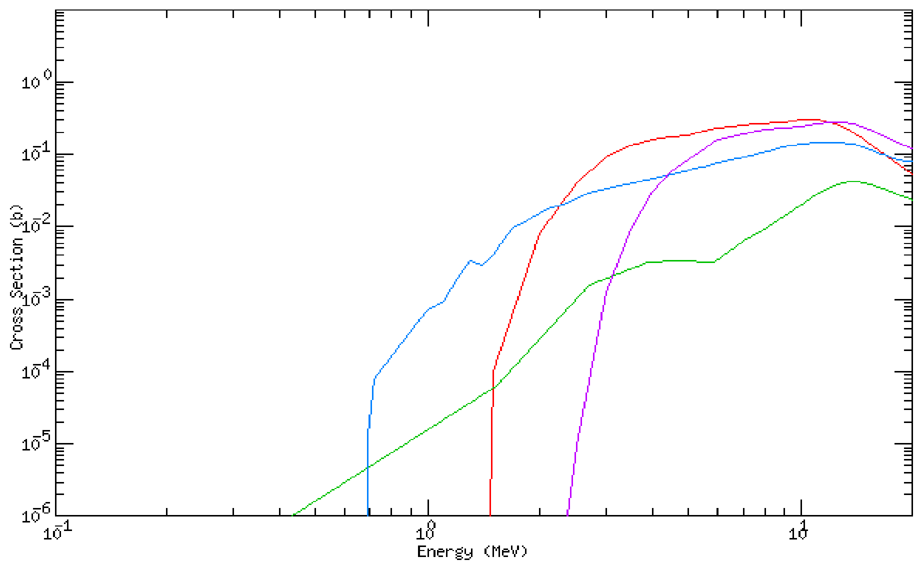
MEASUREMENTS

1. Reactivity Worth in water-filled CT = -$0.80 (rev. 3)
2. Heat Build-up = 95°C at 1MW (Rev 1 & air-cooled)
3. Flux Measurements
   - Au-Al wire (thermal)
   - Ti wire (fast)

Zn-64 to Cu-64
Ti-47 to Sc-47
Ti-46 to Sc-46
Zn-67 to Cu-67




Cave for SS Cask
Main Shield
Lifting sling
Ratchet to remove cap
SSC lid
SS Cask
Tools for wire
Long tweezers

Flux Measurement Irradiation

Two shielded capsules (rev. 4) irradiated in two dry tube locations (E4 and E13)

- DT1: AuAl and Ti wires
- DT2: 0.7gm of natural Zinc Oxide
- 2 hours at 1MW

2nd Flux Run
5/24/2013
Dry Tube 1
1000kW for 6min.
14grams Al-6061
33grams BN
AuAl & Ti wire

2nd Run – natural zinc
5/24/2013
Dry Tube 2
1000kW for 6min.
14grams Al-6061
33grams BN
< 1 gram Zn0