Installation of a Second CLICIT Irradiation Facility at the Oregon State TRIGA® Reactor

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Abstract. The Oregon State TRIGA® Reactor (OSTR) utilizes a cadmium-lined in-core irradiation tube (CLICIT) near the center of the core in support of Ar-Ar geochronological research. Due to significant demand on the CLICIT facility, it was desired to install a second CLICIT facility on the periphery of the core in order to simultaneously irradiate two samples. MCNP was used to model a variety of core locations to determine a feasible location that would not negatively impact current operations. Once the location was chosen, the core was reconfigured to optimize reactor operations. Reactivity effects and control rod worths were predicted through k-code calculations then compared to experimental results.

1. Introduction

The Oregon State TRIGA® Reactor (OSTR) provides irradiation services for customers throughout the world. The two most popular uses of the OSTR involve Argon/Argon (Ar/Ar) geochronology and antimony source production. These services utilize in-core irradiation tubes (ICITs) located in core lattice positions B1 and G14.

The OSTR was converted to Low-Enriched Uranium (LEU) in 2008. The core was initially configured as shown in *Figure 1* with the aforementioned irradiation facilities located in B1 and G14. The core was re-configured in July 2017 as shown in *Figure 2* [1], adding a new cadmium-lined facility in F20 and moving the G14 facility to F12. Two fuel elements were added to compensate for the loss of reactivity due to adding a second cadmium-lined facility. The objective of this was to demonstrate the OSTR MCNP [2] model's ability to predict core behavior.

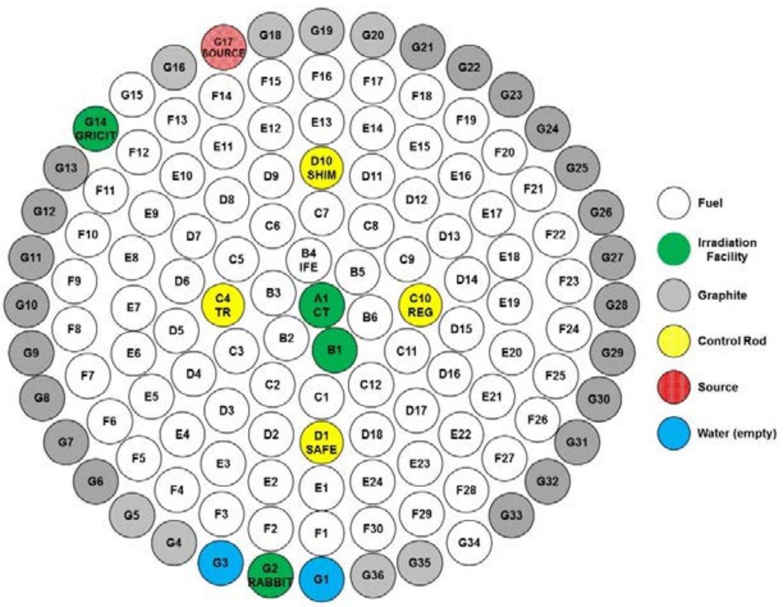

Figure 1 – Diagram of Original LEU Core Configuration

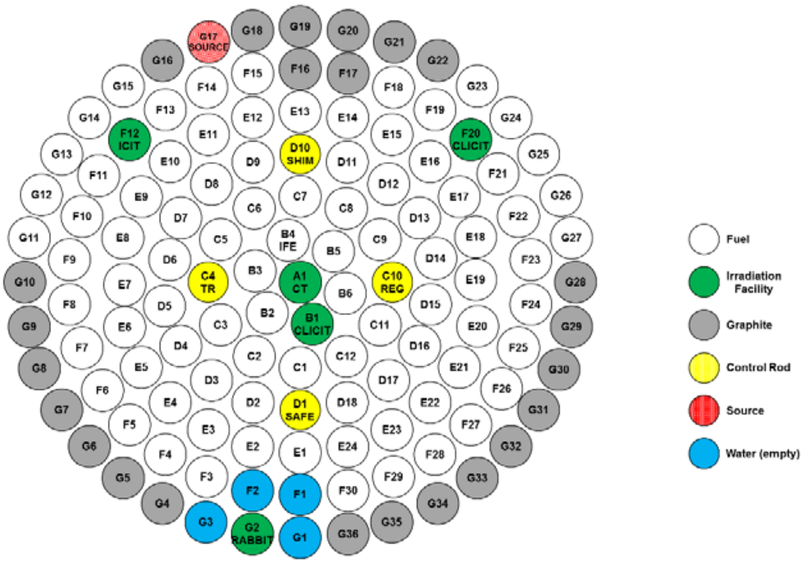

Figure 2 – Diagram of New LEU Core Configuration

2. Background

The ICITs are designed as shown in *Figure 3*. The tubes are welded 6061-T6 aluminum tubes that can fit in any core lattice position in the OSTR. They are secured to the center channel at the reactor top and continuously vented to the monitored bay exhaust stack. These tubes have 20 cm (8 in.) tall removable pedestals installed in order to ensure that samples are located at the axial peak of the neutron flux.

The B1 cadmium-lined in-core irradiation tube (CLICIT) facility is primarily used for Ar/Ar geochronology and has experienced high demand in recent years, sometimes experiencing a 300-hour backlog. Since the OSTR only operates approximately 35 hours a week, this can cause a long wait time for sample irradiation, thus it was desired to install a 2nd CLICIT facility to alleviate the backlog and provide quicker customer service.

During the process of determining where to install a 2nd CLICIT, other configuration changes were proposed to improve the overall operational efficiency of the OSTR. The G-Ring In-core Irradiation Tube (GRICIT) facility in lattice location G14 is primarily used for antimony production. By moving the GRICIT one ring closer to the center of the core into position F12, the antimony samples would experience higher neutron flux, thereby allowing for shorter irradiation times.

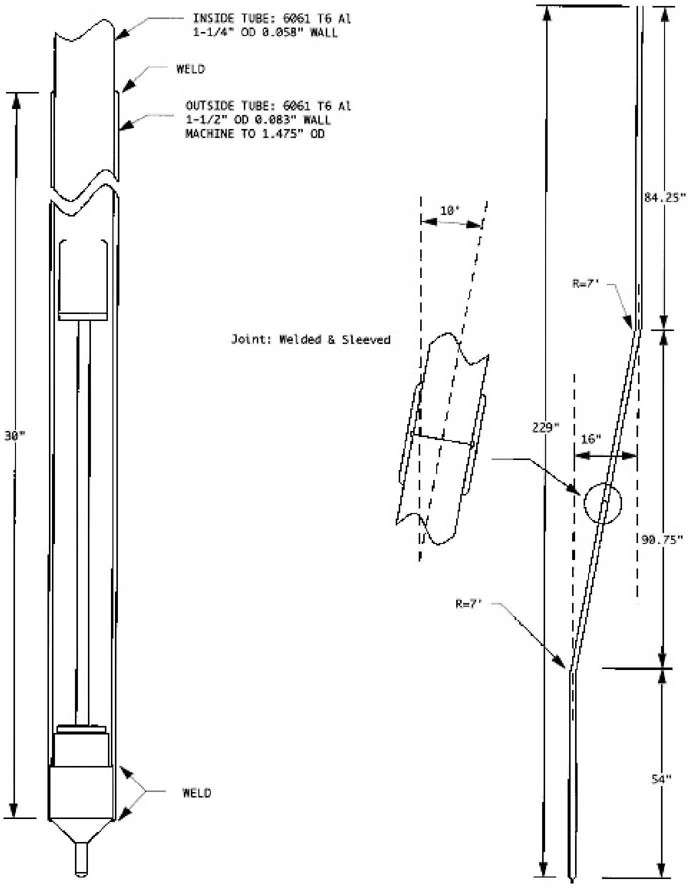

Figure 3 – Cross Section of In-Core Irradiation Tube

3. Finding a Location for the Second CLICIT Facility

3.1. Criticality

The OSTR staff utilizes a highly-resolved MCNP model of the OSTR for various analyses (*Figure 4*) [3].

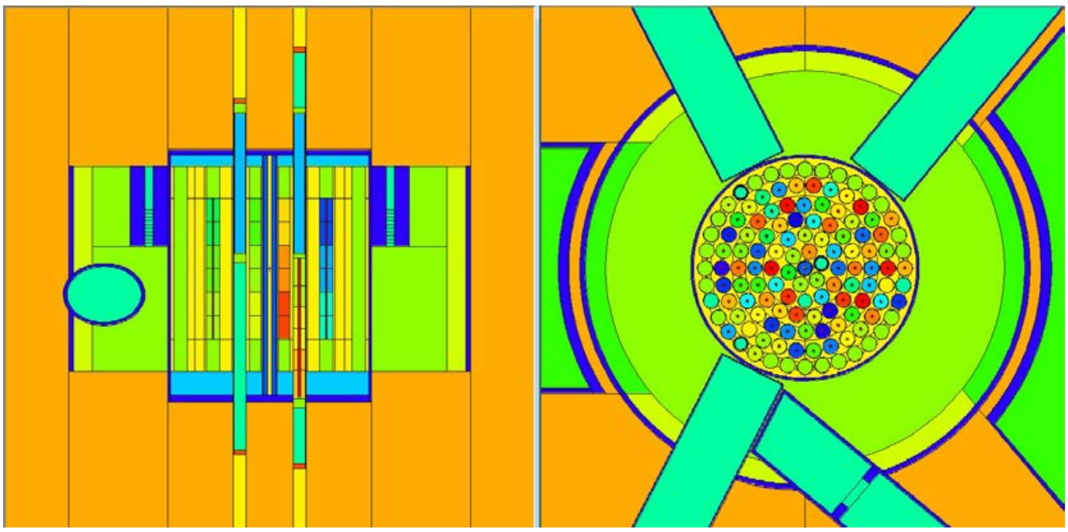

Figure 4 – Sideview and Overhead View of OSTR in MCNP Model

The MCNP model was used to determine the reactivity effects of installing a 2nd CLICIT in various core locations. Grid positions D12, E16, F20 and G24 were chosen since those locations would not interfere with tank components as there were no facilities located in that quadrant of the core.

Table 1 shows the differences in criticality between each core configuration as determined by MCNP. All reactivity values in this report utilize a β_{eff} value of 0.0075 [4].

TABLE 1 – MCNP-PREDICTED CRITICALITY WITH VARYING 2ND CLICIT LOCATIONS

Grid Location	k-effective	Reactivity	Reactivity Difference
No 2nd CLICIT	0.99853	-$0.20	-
D12	0.98776	-$1.65	-$1.45
E16	0.99061	-$1.26	-$1.06
F20	0.99315	-$0.92	-$0.72
G24	0.99705	-$0.39	-$0.19

The original configuration (no 2nd CLICIT) is considered the "critical at 1 MW" configuration and each subsequent iteration was compared to this original configuration. Using known critical rod heights at 1 MW, the base model has 20 cents of negative reactivity bias. The reactivity of the original configuration was subtracted from for each proposed core configuration to determine the reactivity difference. Clearly, the 2nd CLICIT has the largest negative reactivity effect in the D12 position and decreases in effect as the facility is moved to an outer grid location.

3.2. Ratio of Flux in B1 CLICIT to Flux in 2nd CLICIT

The MCNP model divides the interior of each irradiation tube into 1.0 centimeter high air-filled cells and F4 flux tallies were used to determine the axial fluxes. Table 2 shows the ratio of epithermal and fast flux in the B1 CLICIT (with no 2nd CLICIT installed) to the epithermal and fast flux in the respective 2nd CLICIT location. These values were obtained by dividing the tallied flux in the B1 CLICIT (with no 2nd CLICIT) by the tallied flux in the respective 2nd CLICIT location at each axial position then averaging the values.

TABLE 2 – RATIO OF FLUX IN B1 CLICIT TO FLUX IN SECOND CLICIT

Spectrum	D12	E16	F20	G24
Epithermal	1.25	1.54	2.19	3.07
Fast	1.24	1.53	2.28	3.51

These ratios represent the amount that one must multiply the requested irradiation time in the B1 position to receive a similar fluence in the respective grid location. Consistent with the pattern observed in reactivities, the 2nd CLICIT gets less efficient as the facility is moved to the core periphery. The D12 and E16 locations would be highly desirable as they wouldn't require a significant increase in irradiation time, compared to G24 which would require over three times the irradiation time.

3.3. Second CLICIT Location

The OSTR staff determined that the second CLICIT would be located in core lattice position F20 based on the results from the previous two sections. Placing the CLICIT in G24 would have minimal reactivity effects but would take longer to perform irradiations. Locations D12 and E16 were desirable flux locations but have high reactivity costs. Location F20 appeared to have the proper balance of flux and reactivity effect.

4. Results of Core Configuration Change

Once F20 was chosen as the location for the second CLICIT, MCNP was used to model a new core configuration. In order to counteract the $0.72 negative reactivity effect due to installing a second cadmium tube in the core, two spare fresh fuel elements were moved from dry storage into the core, increasing the in-core fuel inventory from 90 to 92 elements (see Figure 2). The fuel was also shuffled, moving 5 elements in front of two of the beam port exit points in an attempt to boost flux in exterior beam port facilities. Fuel was also shuffled from the vicinity of the pneumatic transfer facility (Rabbit) in core location G2 in order to boost the thermal flux and reduce the epithermal flux in that facility. Two reflector elements (graphite rods) were moved to F16 and F17 in an attempt to “push” more flux towards the other side of the core.

4.1. Criticality

Table 3 shows the differences in criticality between the MCNP prediction and the experimental criticality, which was determined to be the first time the reactor was taken to 1 MW critical on a clean core, on Monday, 31 July 2017.

TABLE 3 – CRITICALITY OF MCNP PREDICTION VS. EXPERIMENTAL

Core Configuration	k-eff	Reactivity	Error	Critical Rod Heights at 1 MW (% withdrawn)			
				Transient	Safety	Shim	Regulating
MCNP Prediction	0.99799	-$0.27	$0.02	69	69	69	69
Experimental	1.00000	$0.00	-	68	68	68	68.8

Note that the MCNP predicted k-effective of 0.99799 is deemed “critical” as this incorporates a -$0.27 bias from previous studies [1]. The MCNP prediction matched up incredibly well with the experimental observation. The control rods were slightly more inserted than predicted (one percent insertion equates to 0.15 inches) but this should be within the margins of MCNP error. It is also important to note that the OSTR power channels were previously calibrated in a different core configuration than that shown in Figure 1. During power calibrations, a fuel element was inserted in the B1 position as this was previously the most reactive core configuration. However, after installing the second CLICIT facility, the OSTR staff decided to eliminate other core configurations and the power channels are now calibrated in the core configuration shown in Figure 2.

4.2. Core Excess

Excess reactivity (core excess) is measured experimentally each day by taking the reactor to criticality at 15 watts. Using the control rod calibration curves, the core excess was experimentally determined to be $4.10 on the morning of 31 July 2017. MCNP was used to predict core excess by performing a kcode calculation with all four control rods fully withdrawn to determine the excess reactivity. With all rods withdrawn, MCNP predicts a core excess of $4.14 ± $0.10. The MCNP prediction accurately predicted the core excess.

4.3. Control Rod Worth

The MCNP rod worths were determined by running MCNP with all rods fully inserted, then subsequent runs with one rod fully withdrawn and the other three rods fully inserted. The k-effectives of these runs were subtracted by the all-rods-in to calculate individual rod worth. The MCNP errors represent two standard deviations. Control rod worths were measured experimentally from control rod calibrations performed on 24 July 2017 and these experimental results are compared to the MCNP predictions as shown in Table 4. The control rods are calibrated by the rod pull method, which involves withdrawing each individual control rod at 15 W and measuring the time it takes the reactor power to increase from 200 W to 800 W using a calibrated timer. The rod calibration timer has a specification that it must be accurate within 100 milliseconds, which is approximately 10% error. The rod position indicators are calibrated prior to calibrating control rods and their error may be considered negligible.

TABLE 4 – ROD WORTH COMPARISON BETWEEN MCNP AND EXPERIMENTAL

Core Configuration	Control Rod Worths				
	Transient	Safety	Shim	Regulating	Total Rod Worth
MCNP Prediction	$2.91	$2.04	$2.66	$3.10	$10.71
MCNP Error	± $0.10	± $0.07	± $0.07	± $0.08	± $0.16
Experimental	$2.74	$2.00	$2.58	$3.17	$10.49

The MCNP prediction compares favorably to the experimental results. The transient rod worth is slightly over-predicted and this may be due to it being an air-followed control rod, whereas the other three rods are fuel followed. This over-prediction propagated into the calculation of the total rod worth.

5. Conclusion

MCNP was used to determine a location for the facility and an optimal core configuration was proposed. The prediction was then compared to actual critical data. MCNP appears to accurately predict the criticality changes and control rod worths of the new OSTR LEU core configuration. MCNP has proven to be a useful tool for core configuration changes at the OSTR.

6. Future Work

Geochronologists (i.e., Ar/Ar researchers) require a “J-value” in order to properly analyze their samples. Oregon State University is working with experimenters to determine the J-value of the second CLICIT facility. Flux wire irradiations have been performed in the B1, F12 and F20 facilities and the MCNP model is also being rewritten to attempt to model this flux wire activation. Future modeling will determine the efficacy of MCNP to predict gold wire activation in these facilities.

7. References

[1] SCHICKLER, R.A. “New Core Configuration” RC Report-2017-02. OSU Radiation Center. May 2017.

[2] GOORLEY, T. "MCNP6.1.1-Beta Release Notes", LA-UR-14-24680 (2014).

[3] SCHICKLER, R.A., PALMER, T.S. "Criticality Benchmarking of the Oregon State TRIGA Reactor Using the MCNP Burn Option" Transactions of the American Nuclear Society, Vol. 115, Las Vegas, NV, November 6–10, 2016

[4] KELLER, S.T. *Reactor Startup Report for the Oregon State TRIGA® Reactor Using Low Enrichment Uranium Fuel*. OSU Radiation Center. April 2009.