Kansas State University
# Mechanical & Nuclear Engineering

16 May 2008
50-188

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Gentlemen:

Attached is a report of activities accomplished for initial startup and testing for the renewed facility license No. R-88 for the Kansas State University TRIGA Research Reactor (TAC NO. MC9031). Please contact me if there are any questions at 785-532-6657 or whaley@ksu.edu.

Thank you for your attention,

Paul M Whaley
Nuclear Reactor Facility Manager

cc Daniel E. Hughes, Project Manager
Research and Test Reactors Branch A
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

A020
NRR

## *STARTUP REPORT FOR THE MARCH 19, 2008 KSU REACTOR LICENSE*

This report describes activities conducted to implement a new facility operating license, effective March 19 2008. Implementation was accomplished under a special test procedure approved by the Reactor Safeguards Committee (Attachment I).

### I. PRELIMINARY ACTIVITIES

In accordance with the special test procedure, the status of all Technical Specification surveillances was verified (Attachment I, Appendix I). Two surveillances (calculation of Argon 41 release, verification of reactor bay negative differential pressure) were not required under the previous license. The calculation was performed and documented in an email to the Reactor Safeguards Committee, and is being incorporated into the Semiannual Reactor Manager Report. The negative differential pressure check was added to the daily preoperational checklist.

### II. FUEL MANIPULATION

Core configuration was modified to increase excess reactivity in accordance with approved facility procedures on the effective date of the license. The in-pile rabbit assembly was removed and replaced with a partially-burned fuel element from pool storage. One (of three) instrumented fuel element was configured for the 3-control rod core, and interfered with fuel manipulation in the 4-rod core; the element was replaced with a new instrumented fuel element. One partially burned fuel element located between the safety, shim, and regulating rods was replaced with a new fuel element to enhance excess reactivity.

### III. REACTIVITY LIMIT VERIFICATION

On March 20-21, 2008 the control rods were calibrated in accordance with facility procedures to verify reactivity limits are met in the new configuration. The reactor achieved criticality with the pulse rod removed and the safety rod withdrawn to 781 units. Data collection within the special test procedure assumed a control rod different configuration, and minor changes were required to process reactivity data under the actual configuration. Control rod worth curves are attached.

| | | | |
|---|---|---|---|
| • Total worth of all control rods: | $7.279 | | |
| • Required reactivity addition for critical: | $4.317 | | |
| • Minimum shutdown margin: Required-- | $0.50 | Actual-- | $1.495 |
| • Maximum excess reactivity: Required-- | $4.00 | Actual-- | $2.962 |

### IV. POWER CALIBRATION AND ASCENSION

On March 24, 2008, a power level measuring channel calibration was performed in accordance with facility procedures at 200 kW for 100% indication of 1,000 kW. The calibration point is low in the operating range; during subsequent power ascension, power calculated from heatup rate was observed to be reasonably consistent but slightly higher than indicated power. A formal power calibration at a higher power level could not be performed during initial power ascension and testing since the 200 kW operation abrogated initial conditions for calibration. Since a maximum power level of only 720 kW could be obtained with total core excess reactivity, it is not physically possible to challenge license power level limits. Testing and operations were permitted until a power level calibration could be established on March 31, 2008.

## V. POWER ASCENSION

On March 25 2008 reactor power was increased in accordance with the special test procedure to 400, 500, 600, and 700 kW. In a final step, power was raised to the maximum available of 720 kW. At each step, cooling system response and fuel temperatures were monitored and evaluated.

*Cooling System*

Secondary cooling system and controls were previously modified to support operations at higher power levels. In automatic cooling tower fan mode, fan speed control is based on tower return temperature. The fans energize at a preset speed when return header temperature reaches a low temperature setpoint. Fan speed increases to the maximum preset speed at the high temperature setpoint as return header temperature increases.

The secondary cooling system was previously adjusted for maximum power level operations at 250 kW, complicating assessment of the cooling system; appropriate control setpoints for higher power levels could not be established until actual heat load could be increased under the new license. Equilibrium temperatures were not observed during testing, but temperature increases were controlled and not excessive. The pool was allowed to heat up to an administrative limit of 40°C (Technical Specifications limit of 130°F, or 54.4°C). The control system was subsequently adjusted so that 500 kW for 8 hours results in pool temperatures less than 40°C.

*Fuel Temperatures*

Three instrumented fuel elements (IFE) are in the B-ring. The IFE for measuring channel FT-1 is position B-3. The IFE for measuring channel FT-2 is position B-2. The IFE for measuring channel FT-3 is position B-5. Because reference temperature values are for pool water temperature of 20°C, comparison of observed temperatures to reference values required correcting the observed fuel temperatures for elevated pool temperatures (indicated in Table 1).

**Table1: Power Ascension Temperature Data**

| POWER | FT-1 (°C) | | FT-2 (°C) | | FT-3 (°C) | |
|---|---|---|---|---|---|---|
| | IFE | Corrected | IFE | Corrected | IFE | Corrected |
| 400 | 284 | 281.1 | 231 | 228.1 | 293 | 290.1 |
| 500 | 313 | 308.3 | 251 | 246.3 | 321 | 316.3 |
| 600 | 340 | 328.7 | 273 | 261.7 | 341 | 329.7 |
| 700 | 358 | 342.6 | 289 | 273.6 | 354 | 338.6 |
| 720 | 363 | 345.7 | 291 | 273.7 | 359 | 341.7 |

Temperatures plotted on graphs referenced in the upgrade-implementation procedure (Figure 1) fall within the limits of expected values. Although the observed values are higher than the average reference values for two channels, the difference between observed and reference values decreases as power increases; it is likely that at some power level between 700 and 1000 kW the observed power will be less than the reference.

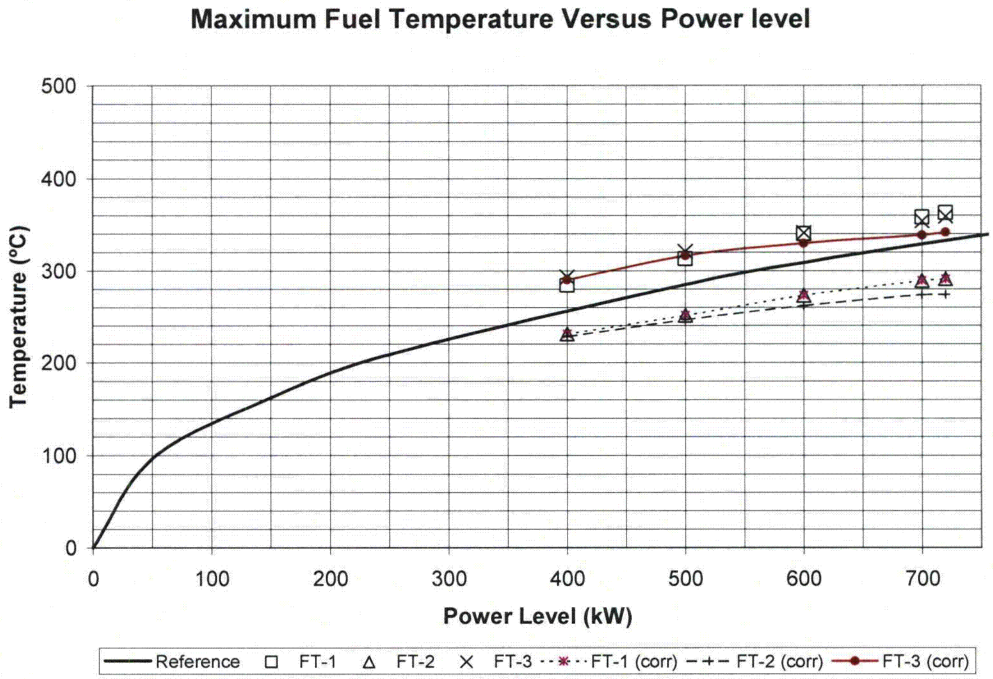



*Figure 1: Power ascension temperature data of Table 1 plotted against reference expected value. Symbols indicate fuel temperature measuring channel indication with data corrected for elevated pool temperature represented by lines.*

The fuel element with the highest temperature is not instrumented, and fuel thermocouples in an IFE are not located at fuel centerline. Because fuel temperature values were higher than the average value, additional analysis was conducted to evaluate the maximum core temperatures. The relationship between the IFEs and the unmonitored element was calculated, and the monitored temperature versus the peak centerline temperature within the IFE. The potential error in the power calibration was also evaluated.

*IFE Compared to Fuel Element with Peak Power*. The instrumented fuel elements designated by FT1 and FT3 are located in fuel positions adjacent to the pulse rod, which is fully removed during normal operations. An MCNP calculation was performed to determine the distribution of power across the core for a slightly supercritical configuration and also for all rods out. The ratio of individual B-ring fuel element fission heat generation to the core average was calculated (Figure 2). The fuel position between IFEs for FT1 and FT3 has a slightly elevated power production.

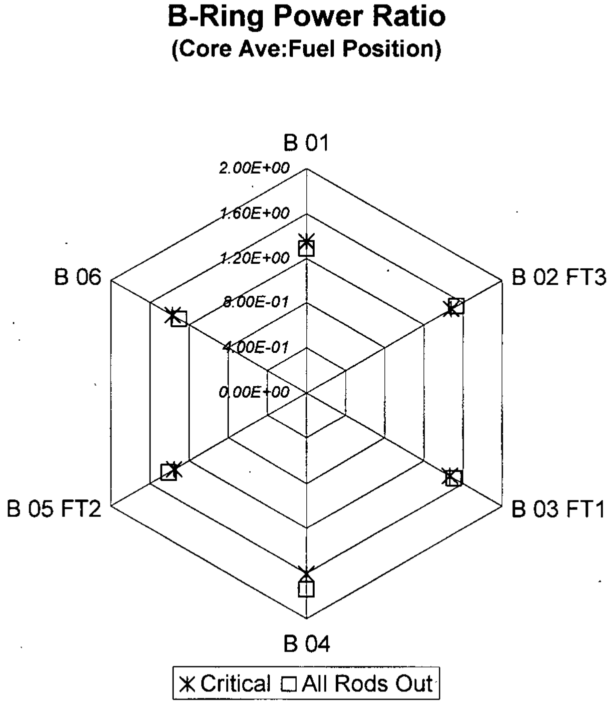



*Figure 2: The ratio of B-Ring element heat generation rate to the core average for all fuel rods calculated by MCNP5. Squares are data with control rods in an approximate critical configuration, and the alternate symbol with control rods fully withdrawn.*

*Thermocouple Location.* Fuel rods have a diameter large with respect to neutron migration length; consequently there is a distribution of power biased towards the outer sections of the fuel rod. Power distribution shapes the temperature profile, with the variation from fuel centerline temperature to the outer radius of the fuel (neglecting heat transfer except in the radial direction) calculated by:

$$\frac{1}{r} \cdot \frac{d}{dr}\left[k \cdot r \cdot \frac{dT}{dr}\right] + q''' = 0$$

MCNP calculations (originally performed for and reported in the Safety Analysis Report) show power distribution across an individual fuel rod. General Atomics indicates the thermocouples are located about 0.3 in. (0.76 cm) from the inner surface of instrumented fuel elements. As a consequence, the measured temperature is comparable to the peak temperature (Figure 3).

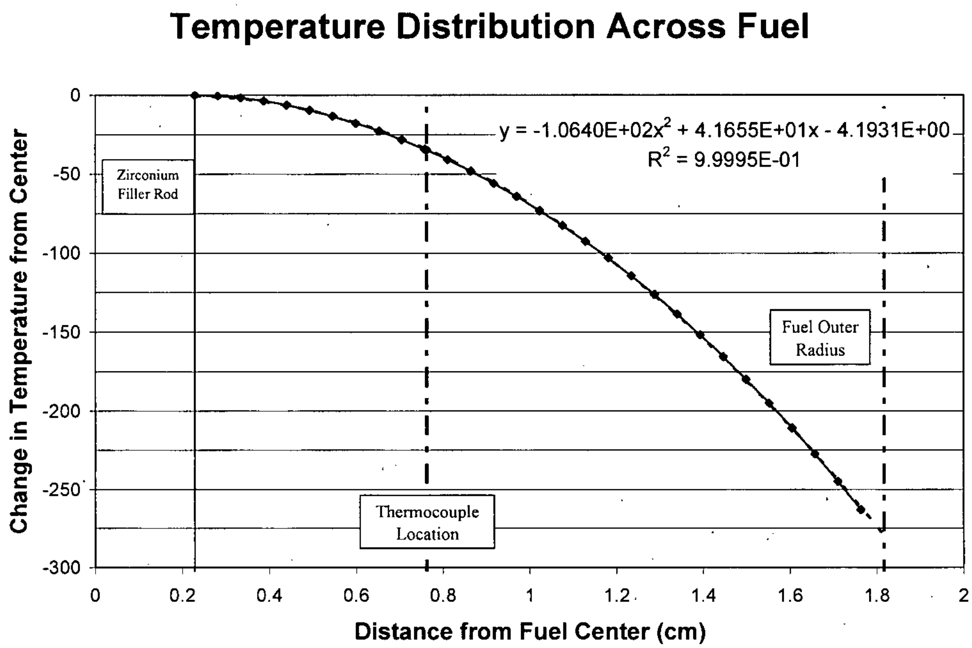



*Figure 3: Decrease in temperature from centerline calculated for full power operations.*

These results are within the fuel rod; indicated temperature correlates to temperature differences across the gap, cladding, and water as well as the fuel. The difference between the maximum temperature decrease within the fuel is about 10% of total temperature difference across the fuel. The maximum fuel element temperature in the core is within about 8% of the highest reading indicated by the IFE measuring channels.

*Power Level Measuring Channel Calibration.* As previously noted, calculation of power from heat up rate following initial calibration indicated actual power is higher than indicated power. The power level calibration completed for higher power operation showed an indicated 600 kW power level was actually 639 kW. After the calibration at 600 kW was complete, the observed fuel element temperatures correlated more closely to the expected fuel temperatures.

In conclusion, two fuel element temperatures were slightly higher than the expected average with one lower, but all well within the range of expected values.

## VI. RADIATION SURVEYS

Radiation surveys were conducted during power ascension under supervision of the KSU Radiation Safety Officer. Additional radiation surveys were conducted on March 27-28, 2008, to validate experiment shielding.

It was observed during operation for calibration at 600 kW that if primary cooling is secured during high power operations the pool surface monitor exceeds 500 mR $h^{-1}$. With primary cooling operating, the radiation levels fall to less than 100 mR $h^{-1}$. Primary cooling is normally operated at high power levels. Access to the pool (22-foot level) is visible from the control room, and the visual surveillance system can monitor the 22-foot level. Radiation levels on the 22-foot level are indicated in the control room.

Radiation levels were generally found to be acceptable, with one local area at the north west beam port experiment installation higher than desired. The experiment shielding was modified and subsequently demonstrated to be more effective. A revision to the calibration procedure will be submitted for Reactor Safeguards Committee review that restricts access to the 22-foot level during data collection for calibration.

## VII. POWER LEVEL CALIBRATION

On March 31, 2008, the final power level calibration was completed, with an indicated power level of 600 kW corresponding to an actual power level of 639 kW. Linearity of the heatup rate was not as consistent as previously experienced. Bubbles were observed in the convection flow from the core were observed in the pool, and is the likely cause for the non linearity.

The KSU reactor facility does not have experience with the bubble phenomena that occurs at power levels available under the new license, and this effect was unanticipated. Two higher-power reactors were contacted, and indicated this phenomena is a characteristic of high power operations. The bubbles are likely related to three interrelated characteristics: changes in solubility of air in water with temperature, nucleate boiling, and pool boiling characteristics of water-air systems. There may an additional or contributing factor in the buildup of gas in pool water associated with radiolytic decomposition of core water.

The pool is open to the reactor bay environment, and dissolved air in the pool establishes equilibrium with reactor bay air based on water temperature and solubility constants for atmospheric gases. Heat transfer from fuel elements to coolant changes solubility locally in the core. Water temperature vertically along a fuel element during operations was analyzed using TRISTAN (FORTRAN code, ORNL RSICC PSR-537). Hydraulic parameters were taken from the Safety Analysis Report, inner-ring cooling inlet-aperture specified in GA-3399, and observed pool temperatures. At 400 °C, a 17 °C temperature rise is calculated along the fuel element; at 720 °C, a 24 °C is calculated along the fuel element. Over the range of observed operating temperatures, solubility decreases as temperature increases by approximately 1.4 mg $l^{-1}$ for oxygen and 12 mg $l^{-1}$ for nitrogen. Therefore, as water is heated by fuel elements nitrogen and oxygen gas are likely to evolve from the core region.

TRISTAN predicts boiling regime for specified thermal hydraulic parameters. Nucleate boiling is predicted to occur for the K-State core beginning at about 100 kW (for a small section of fuel rod). At 400 kW nucleate boiling is predicted for the full length of the fuel rod. At 720 kW the minimum DNBR for the fuel rod is calculated at 5.60 (Bernath correlation) and 2.96 (compared to a nominal 137 W $cm^{-2}$). At 1250 the minimum DNBR ratios are 4.68 (Bernath correlation) and 2.95 (compared to the nominal 137 W $cm^{-2}$). Therefore nucleate boiling is expected during high power operations, and the margin to DNB is large.

Lu and Peng (*Nucleate Boiling Modes of Subcooled Water on Fine Wires Submerged in a Pool*, Experimental Heat Transfer, 19:95–111, 2006) identify a regime for nucleate boiling in a system of water with air where heat transfer nucleation sites provide conditions permitting evolution of gas from solution. Large, stable bubbles of mostly gas are formed. When the heat transfer transitions to fully developed nucleate boiling, small bubbles that collapse after leaving the surface are observed (i.e., a traditional "nucleate boiling") as the dominant characteristic. Therefore bubbles that reach the pool surface are a normal characteristic of TRIGA reactor operation at high power.

Calibration procedures from three TRIGA reactors were obtained to determine if the methodology could be improved based on other research reactor experience. One lower-power facility uses the same method as KSU, with a different constant (because of a larger pool) correlating the rate of temperature rise to thermal power. One higher-power reactor uses a mixer in the reactor pool to support the calibration process. The other reactor uses cooling system temperature differences and flow rates to calculate heat transfer. This information is under consideration for potential changes to the KSU reactor power level calibration procedure (which under 10CFR50.59 may require NRC approval prior to implementation).

Visible evidence of bubbles was somewhat unexpected, but (1) experience at other facilities and (2) methodology examining development of nucleate boiling independent of prior Safety Analysis Report work indicates this to be a normal condition, with a large margin to DNBR. The established method for power level measuring channel calibration was adequately implemented but the method may have room for improvement.

## IX. PULSING OPERATIONS

A series of pulsing operations was performed over April 1-4, 2008 using reactivity additions of $1.00, $1.50, $2.00 and the maximum available of $2.85 (Table 2). Two pulses were performed for each pulsed reactivity value. The columns in the table below labeled "energy," "Max Pwr," and "FWHM" were obtained through a LabView application. Columns in the table below designated FT represent maximum temperature data for three instrumented fuel elements in the B-ring. The NV and NVT columns are data from the NPP-1000, power and pulsing channel. The LabView application did not record data on four of the pulses.

Table 2: Pulse Data

| Date | No | React | Energy | Max Pwr | FWHM | FT1 | FT2 | FT3 | NV | NVT |
|---|---|---|---|---|---|---|---|---|---|---|
| 3-Apr-08 | 457.20 | 1.00 | 6.30 | 1.05 | | 117 | 112 | 124 | 0 | 0 |
| 1-Apr-01 | 457.21 | 1.00 | 6.60 | 1.10 | 7.60E-3 | 119 | 114 | 127 | 0 | 0 |
| 3-Apr-08 | 458.00 | 1.50 | 25.51 | 52.79 | 6.08E-2 | 222 | 222 | 241 | 0 | 0 |
| 3-Apr-08 | 459.00 | 1.50 | 25.78 | 56.85 | 6.26E-2 | 224 | 224 | 243 | 20 | 0.5 |
| 3-Apr-08 | 460.00 | 2.00 | | 221.30 | 3.03E-2 | 288 | 289 | 313 | 150 | 1.9 |
| 3-Apr-08 | 461.00 | 2.00 | | 226.00 | 2.92E-2 | 289 | 291 | 313 | 150 | 1.9 |
| 3-Apr-08 | 463.00 | 2.50 | 296.36 | 515.66 | 2.08E-2 | 356 | 359 | 383 | 240 | 3.5 |
| 3-Apr-08 | 464.00 | 2.50 | 296.53 | 514.00 | 1.04E-2 | 355 | 357 | 382 | 240 | 3.25 |
| 3-Apr-08 | 465.00 | 2.85 | 302.96 | 778.60 | 1.30E-2 | 394 | 405 | 428 | 245 | 4.75 |
| 4-Apr-08 | 466.00 | 2.85 | | | | 402 | 406 | 431 | 240 | 4.8 |
| 4-Apr-08 | 467.00 | 2.85 | | | | 401 | 404 | 429 | 160 | 4.8 |

The LabView application monitors signal from a picoammeter connected to a detector inserted in the central thimble (added pulse channel). The picoammeter signal is linear, but the gain of the picoammeter required correction of the LabView-indicated power level (Figure 4).

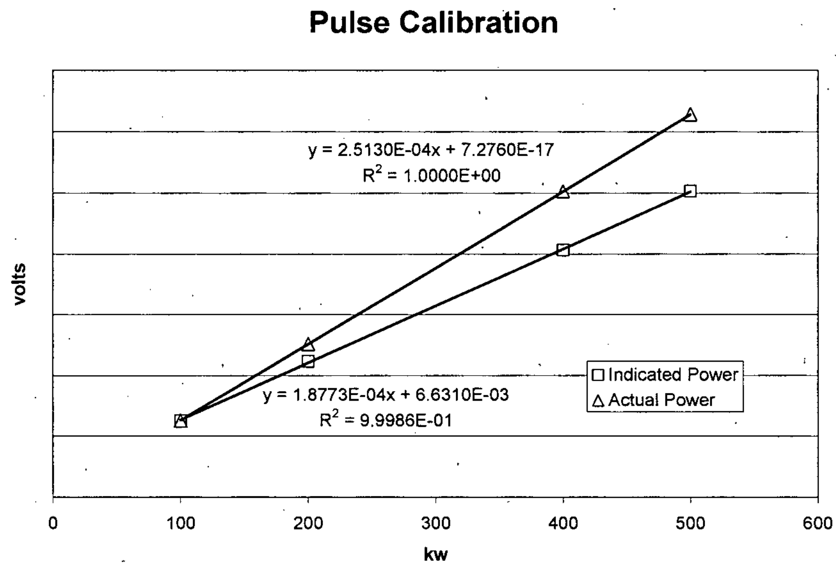



*Figure 4: Calibration data for the added pulse channel.*

Correction for calibration will be implemented directly in LabView from calibration of the added pulse channel in a future revision to the pulse monitoring program. Maximum power and maximum fuel element temperature were compared to reference values (Figures 5 and 6 respectively); other reference parameters could not be compared.

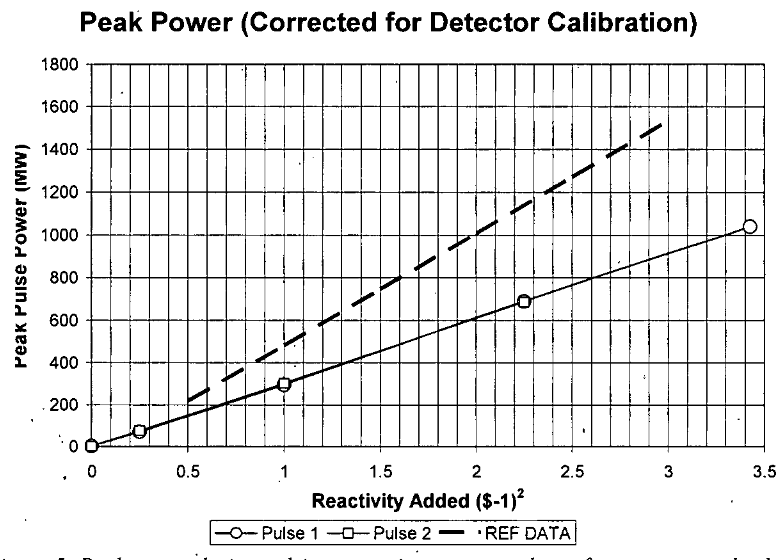



*Figure 5: Peak power during pulsing operations compared to reference expected values.*

Peak pulse power deviates from the reference value; the reference value is taken from a TRIGA reactor using a different core lattice, and may reflect different neutronic parameters. Other parameters for which reference values were available are more sensitive, and therefore less comparable, possibly complicated by calibration and time-response characteristics of pulse monitoring instrumentation. The slope of the observed peak temperature is also different from the slope of the reference curve, which may be attributed to the neutron lifetime for the K-State core. Both peak power and pulse fuel temperature show stable, predictable behavior from pulsing operations.

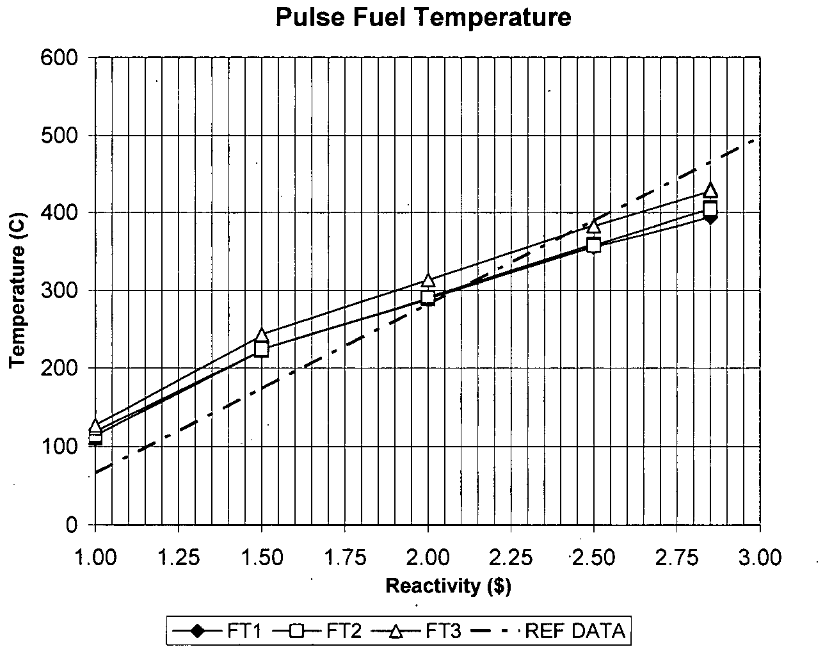



*Figure 6: Peak fuel temperature during pulsing operations compared to reference expected values*

## X. CONCLUSION

As expected, maximum operating power level with current core loading is about 700 kW. Steady state operations are limited by excess reactivity, which is near the maximum physically possible with the K-State core grid plate and the type of fuel authorized under Technical Specifications. One unfueled space is currently occupied by a neutron source, and fuel (reactivity worth about $0.40) could be used to increase excess reactivity to about $3.20, well within the Technical Specification limit of $4.00. Increasing excess reactivity to permit extended operations at full power may require a license amendment to permit the use of 12% TRIGA fuel, with specific controls on the location of the elements within the core to ensure power peaking factors remain within current analysis.

All reactivity limits are met by a large margin. Fuel temperature limits are met during normal and pulsing operations to available excess reactivity.

Methods for conducting power level measuring channel calibration are being evaluated to determine if improvements in data collection and analysis or a different technique would be more appropriate.

Bubbles are observed during operations and (according to experience at other TRIGA reactors and by a code designed to analyze TRIGA reactor behavior) to be a normal characteristic.

***K-State Reactor Startup Report***
***ATTACHMENTS***

1. Implementation and Test Plan for KSU Reactor Power Upgrade
2. Control Rod Worth Curves
3. Power Ascension Radiation Surveys

**SCOPE**

This procedure provides direction for testing and initial operations under the licensed maximum power level of 1,250 kW operations.

This procedure addresses:

- Performance of pre critical checks that verify all Technical Specifications have been met
- Control rod calibrations following fuel loading to increase excess reactivity
- Verification that reactivity limits have been met
- Power level calibration for 100% indication at 1,000 kW
- Adjustment of pool surface monitor alarm setpoint
- Surveys to verify acceptable radiation levels and appropriate controls
- Comparison of fuel temperature and reactivity deficit to expected values
- Verification that the cooling system functions
- A series of pulsing operations, starting with low pulse worth and increments to the maximum available reactivity within Technical Specifications limits

**DISCUSSION**

The KSU TRIGA Mark II reactor has historically required approximately $4.20 of reactivity to achieve criticality; with the current core configuration, Core III-1 requires $5.40.

The 250 kW license required that the pulse rod have a nominal worth of $2.00; the 1,250 kW license does not have a Technical Specification limit for the pulse rod, but the pulse rod in the C ring is expected to have a worth of approximately $3.00.

The worth of the pulse rod in the C ring while under the 250 kW license was artificially depressed by placing a water-filled aluminum tube next to the pulse rod. This arrangement permitted configuring the control rods to support the 1,250 kW license prior to issuance of the license.

The worth of fuel elements in the C ring have been measured with respect to a water void to be approximately $1.00.

If the pneumatic tube is removed form the core to accommodate the addition of another fuel element, operations with the rabbit in place may require additional reactivity checks to ensure the control rod worth curves are properly calibrated.

Calculations conducted for the Illinois Advanced TRIGA (reference 2) are provided in Appendix I to provide values for comparison of expected fuel temperature, reactivity loss due to fuel temperature, and reactivity loss for operation at power.

## LIMITS AND PRECAUTIONS

KSU Technical Specifications for operation with a maximum power level of 1,250 kW has reactivity limits for excess reactivity of $4.00 and a minimum shutdown margin with the most reactive rod fully withdrawn of $0.87.

## PREREQUISITES

Approved license permitting a maximum of 1,250 steady state thermal power.

For 36 hours prior to calibration, the following conditions are required to be met:

- Operations limited to < 1 kWh,
- No secondary, cooling operation
- Pool water 20 ± 5 °C

## INSTRUCTIONS

1. **VERIFY** Technical Specifications are met
2. **STARTUP** to 10 watts using OP-15, *Reactor Startup*
3. **SHUTDOWN** the reactor using OP-16, *Reactor Shutdown*
4. **REMOVE** the experiment thimble from position C-8 AND **SECURE** the tube to the pool wall
5. **REMOVE** the in-core rabbit tube from position F-23 AND **SECURE** the tube to the pool wall

Applies to Step 6-7

**NOTE**

Inspection includes verification of serial number, visual inspection, and verification of elongation and bend meet Technical Specification requirements

Steps 6 and 7 may be performed sequentially of each element, or inspections of both preceding loading

6. **INSPECT** two fuel elements
7. **LOAD** fuel positions C-11 and F-23
8. **STARTUP** to 10 watts using OP-15, *Reactor Startup*

Applies to Step 9

**NOTE**

Fuel loading affects control rod worth calibration, so the reactivity worth based on previous calibration may not be accurate

Applies to Step 9

**CAUTION**

Technical Specifications limit on excess reactivity is $4.00; excess reactivity preceding Step 7 should be approximately $1.1; if the reactivity difference in Step 9 exceeds $2.90, reactivity measurements in step 10 should begin with measurements required to verify excess reactivity

9. **RECORD** reactivity difference between Step 2 and Step 8, based on previous control rod worth calibrations

Applied to Step 10

**NOTE**

The pulse rod should be worth more than $3.00, and a combination of rod drops and positive period measurements may be required to get reactivity worth for the control rod at the fully withdrawn position

Applies to Step 9

**WARNING**

If excess reactivity is > $4.00, DO NOT proceed until excess reactivity is reduced to less than $4.00

10. **PERFORM** reactivity verifications for critical rod positions

11. **VERIFY** reactivity limits are met

Excess reactivity

(1) Transient Rod worth fully withdrawn: $2.851

(2) Safety Rod worth fully withdrawn: $1.783

Shim Rod:

(3a) Worth fully withdrawn: 1.979

critical Safety Rod via Shim

Critical position: 781

(3b) Critical Worth: $1.483 (3c) Difference {(~~3a~~ 2)- (3b)}: 0.299

Regulating Rod:

(4a) Worth fully with drawn: 0.665

Critical position: NA

(4b) Critical Worth: NA (4c) Difference {(4a)- (4b)}: NA

Pool bulk temperature: 22.2°C Associated Reactivity: (5) -0.016

Source worth ($0.025 inserted) (6) 0 (out)

Total Control Rod Worth:

(1) + (2) + (3a) + (4a) (7) 7.278

2.851 + 1.783 + 1.979 + 0.665

Critical Reactivity Addition:

(1) + (2) + (3b) + (4b) - (5) - (6) (8) 4.318

2.851 + 1.483 + 0 + 0 - (-0.016)

_______________

Excess Reactivity

(7) – (8) $ 2.960

7.278 - 4.318

Minimum Shutdown Margin

NOTE: critical on safety at 781

(2) + (3b) + (4b) - (5) - (6) $ 1.466

**IF** "Excess Reactivity" > $4.00,

OR

**IF** Minimum Shutdown Margin < $0.50,

THEN

**REMOVE** one fuel element AND **REPEAT** steps 10 and 11.

12. **CALIBRATE** the shim and regulating rods over full span of rod movement

| Applied to Step 13<br>**NOTE** |
|---|
| For 36 hours prior to calibration, the following conditions are required to be met:<br><br>• Operations limited to < 1 kWh,<br>• No secondary, cooling operation<br>• Pool water 20 ± 5 °C |

13. **STARTUP** using OP-15, *Reactor Startup*, or **INCREASE** power to 200 kW

14. **RECORD** data (fuel temperature, control rod position) AND **COMPARE** the associated reactivity deficit to data in Attachment II

15. **CALIBRATE** NMP-1000, Nuclear Multi-range Power channel to indicate 20% power at 200 kW

16. **ADJUST** pool surface monitor alarm setpoint as required to prevent spurious alarms during the following power increase

17. WHEN pool surface monitor exceeds 100 mrem/hr, **POST** the 22 foot level as a high radiation area AND prohibit access WHILE the area is a high radiation area

18. **ADJUST** pool surface monitor:

- "ALERT" setpoint 100 mrem/h
- "ALARM" setpoint 500 mrem/h

19. **INCREASE** power to 500 kW

| Applies to Step 19<br>NOTE |
|---|
| A complete calibration following Procedure 2, "Annual Power Level Calibration," is not possible because of operating history of the previous step. |

20. **VERIFY** power level calibration

21. **VERIFY** cooling system function

22. **INCREASE** power in 100 kW steps to a maximum of 1,000 kW AND at each increment,

    22.1. **VERIFY** cooling system function

    22.2. **VERIFY** power level calibration

23. At maximum power level for which steady state operation is possible,

    23.1. **PERFORM** radiation surveys

    23.2. **ENSURE** applicable radiation area postings are accurate

    23.3. **ADJUST** pool surface monitor setpoint to 150% of the steady state radiation level

24. **SHUTDOWN** using OP-16, *Reactor Shutdown*

| Applies to Step 25<br>NOTE |
|---|
| The new calibration of NLW-1000, the wide range power level indicator, may place the detector so that the source interlock will not clear with the source in F-10; if the source interlock will not clear, the source may be placed in an alternate core or RSR position followed by<br>• verification that reactivity limits are met<br>• verification that power level calibration is not changed |

25. **PULSE** the reactor using Experiment 23 and reactivity values from $1.00 up to the lesser of maximum available pulse rod reactivity or $3.00.

26. **COMPARE** pulse data to expected pulse data in Appendix II

**DEFINITIONS**

None.

**REFERENCES**

1. Kansas State University Research Reactor Technical Specifications, 2008

2. Safety Analysis Report for the Illinois Advanced TRIGA, Section XIII (Initial Tests and Operation), 1967

3. Amendment No 4 to the Safety Analysis Report for the Oregon State TRIGA Reactor (OSTR), 1975

Approved: KSU Reactor Safeguards Committee

| M. H. Hosni | 3/17/08 |
|---|---|
| M. H. Hosni, RSC Chairman | Date |

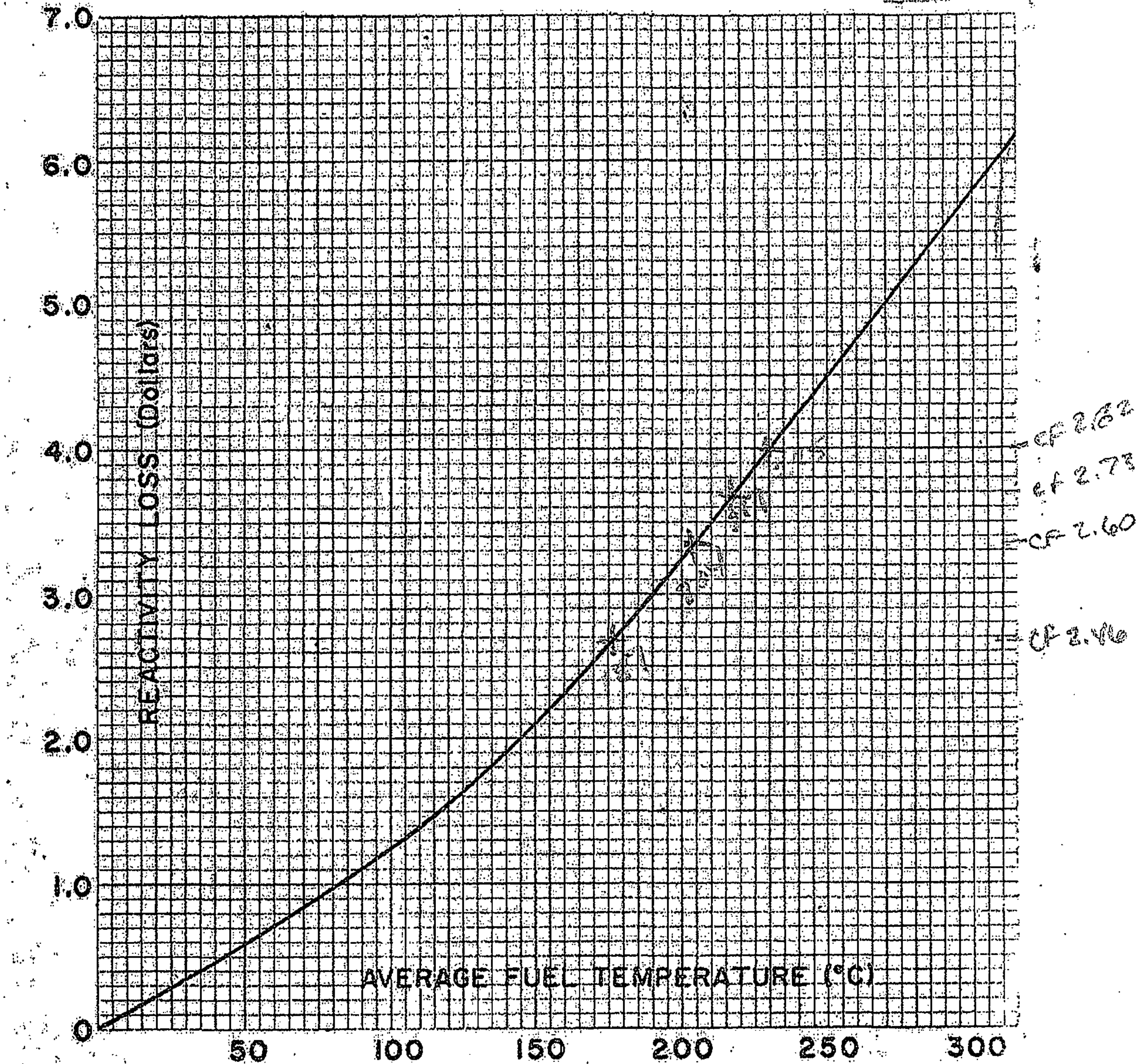
| Appendix 1: Technical Specifications Requirements | Page 1 of 2 | |
|---|---|---|
| | 03/14/08 | Rev 0 |

Safety Limit, fuel temperature -- 1150 peak, 750 steady state
Limiting Safety System Setting -- 1,250 kW

| Item | specification(s) | Surveillance | Frequency | Criteria | Procedure | Last Done |
|---|---|---|---|---|---|---|
| Core reactivity | max excess $4.00 ok | Verify excess reactivity | Semiannual | Excess < $4.00 | ~~Manager Audit~~ | 3/17/08 |
| | | | after experiments with measurable positive reactivity | Excess < $4.00 | OP 15 | 3/17/08 |
| | SDM $0.5 most reactive rod out ok | Verify SDM | semiannual | > $0.5 SDM | Manager Audit | 3/17/08 |
| | -- | control rod worth | biennially | N/A | ~~Exp 6~~ | 4/2/07 Done |
| Pulsed mode | transient rod positioned to less than $3.00 ok | < $3.00 | prior to pulsing | Pulse worth < $3.00 | Exp 23 | 1/17/08 (last pulse) |
| Safety channel safety channel & control rod operability | startup channel count rate > minimum sensitivity ok | Verify channel > min sensitivity | daily | CR > min sensitivity | Daily checklist | 3/17/08 |
| | operating: 2 power level | Channel test ok | daily | Channel operating | Daily checklist | 3/17/08 |
| | | Calibration | annual | Calibration | OP 2 | 4/9/07 |
| | | HV test ok | daily | Channel operating | Daily checklist | 3/17/08 |
| | operating: 1 pool temp | Calibration | annual | Calibration | ~~OP 28 (new)~~ | 3/18/08 |
| | operating: 1 bay differential pressure | Calibration | annual | Calibration | ~~OP 28 (new)~~ | 3/18/08 |
| | operating: 1 fuel temp | Calibration | annual | Calibration | ~~OP28 (new)~~ | 3/18/08 |
| | operating: 22 foot area rad monitor | Channel test ok | daily | Channel operating | Daily checklist | 3/17/08 |
| | | Calibration ok | annual | Calibration | OP 3 | 5/21/07 |
| | operating: 0 or 12 footarea monitor | Channel test | daily | Channel operating | ~~Daily checklist~~ | 3/18/08 |
| | | Calibration | annual | Calibration | OP 3 | 3/18/08 |
| | operating: continuous air monitor | Channel test ok | daily | Channel operating | Daily checklist | 3/17/08 |
| | | Calibration ok | annual | Calibration | OP 8 | 5/15/07 |
| | operating: exhanust plenum monitor | Channel test ok | daily | Channel operating | Daily checklist | 3/17/08 |
| | | Calibration | annual | Calibration | ~~OP 8~~ | 3/18/08 ← Look @ OP 8 |
| | control rod drop time < 1sec | Measure drop time ok | annual | < 1 sec | OP 4 | ~~5/21/07~~ 11/21/07 |
| | 2 power level scram | Test scram ok | Daily | SCRAM | Daily checklist | 3/17/08 |
| | manual scram bar | Test scram ok | Daily | SCRAM | Daily checklist | 3/17/08 |
| | interlock for pulse mode/standard movement | Test interlock ok | semiannual | Rod motion inhibited | OP 5, OP 12 | 12/24/07 |
| | interlock for pulse rod coupling except in pulse mode | Test interlock ok | semiannual | Rod motion inhibited | OP 5, OP12 | 12/24/07 |
| | ROD OPERABILITY | check control rods for corrosion & damage ok | Biennial | Visually OK | OP 1 | 3/29/07 |
| | PULSING OPERABILITY | functional test pulse rod ok | prior to pulsing | System OK | OP 12 | 1/17/08 |

| Item | specification(s) | Surveillance | Frequency | Criteria | Procedure | Last Done |
|---|---|---|---|---|---|---|
| | | pulse rod drive cylinder and air supply checks | semiannual | Visually OK | OP 6 | 12/9/07 |
| Gaseous effluent | in leakage | negative bay dp | Daily | Inleakage | Daily checklist | 3/17/08 → not on checklist |
| | Ar 41, 30 Ci per year | Calculate release | Annual | < 30 Ci | ~~Management Audit~~ | |
| | -- | channel test air monitor | Daily | | Daily checklist | 3/17/08 |
| experiments | single experiment < $2.00 worth | Estimate reactivity worth | evaluate prior to insertion | Expt worth < $2.00 | ~~OP 15~~ | N/A |
| | sum of experiments that can cause reactivity change < $2.00 | if >$0.40 measure & record worth | evaluate prior to insertion | if >$0.40 , verify expt < $2.00 | ~~OP 15~~ | N/A |
| | irradiation holders prevent release into pool | Inspect irradiation holder | evaluate prior to insertion | Holder will prevent release | ~~OP 15~~ | N/A |
| Fuel integrity | elongation | inspection & measurement | 500 pulses or exceeding LSSS | < 1/8 in. | OP 10 | 3/31/07 |
| | bend | inspection & measurement | 500 pulses or exceeding LSSS | < 1/8 in. | OP 10 | 3/31/07 |
| | FUEL INTEGRITY | 1/3 core visual | annual | Visual OK | OP 10 | 3/31/07 |
| Pool water | <130°F with demineralizer flow | Check temperature | channel operable | <130°F, w demin flow | Console Logs | 3/17/08 |
| | conductivity < 5 uSv | Check conductivity | daily | < 5 uSv | Daily checklist | 3/17/08 |
| | | Check conductivity | at least 30 days | < 5 uSv | Surveillance Check sheet | 3/17/08 |
| | water level > 13 feet over core | Check level | daily | water level > 13 feet | Daily checklist | 3/17/08 |
| maintenance retests | evaluate maintenance for potential to affect operability | Evaluate maintenance | Following maintenance | Potential effect on operability | ~~OP 15~~ | N/A |
| | complete applicable surveillance prior to operations | Retest requirements | Following maintenance | Specific to surveillance | ~~OP 15~~ | N/A |

III-30

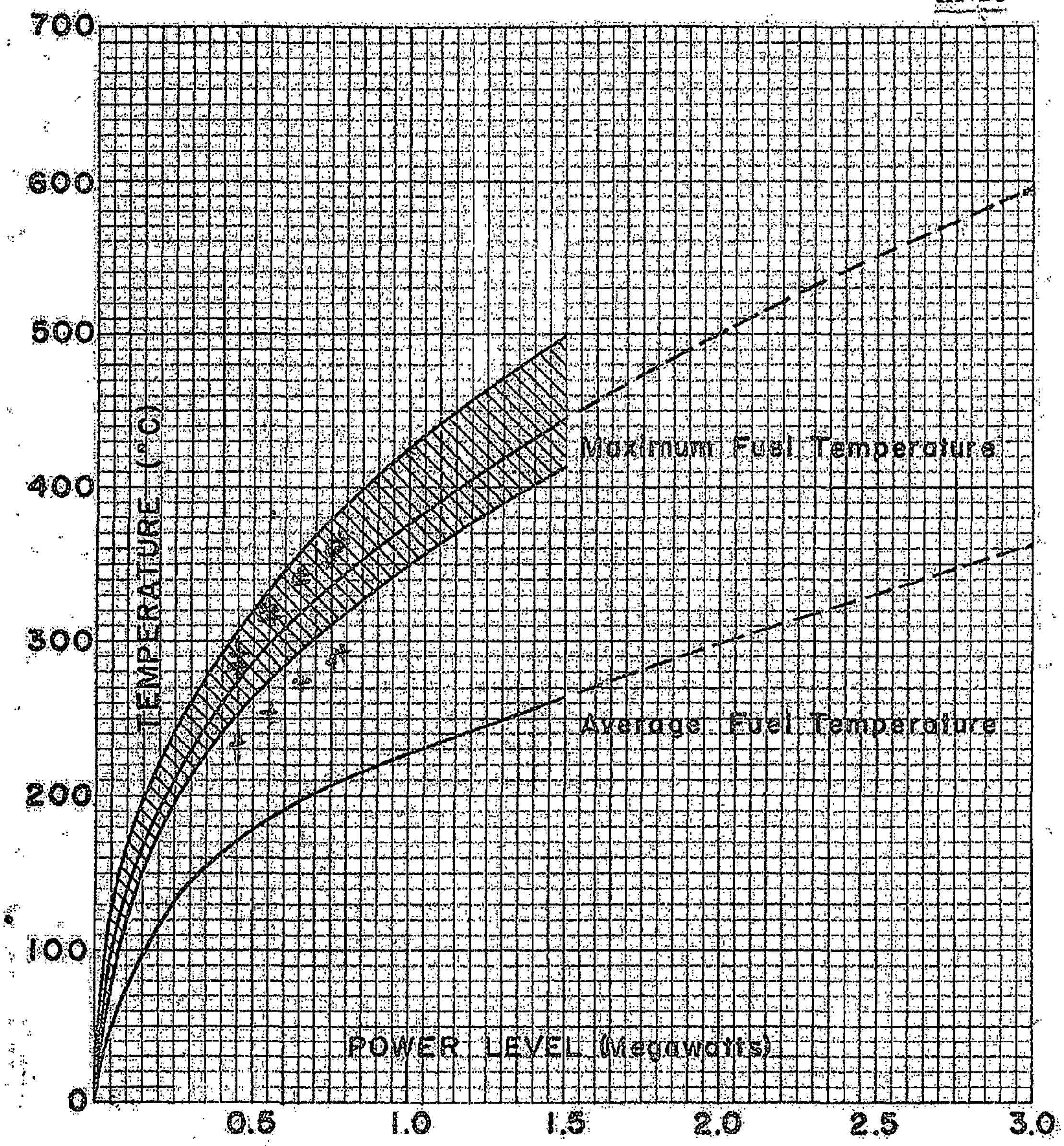



AVERAGE FUEL TEMPERATURE

Vs.

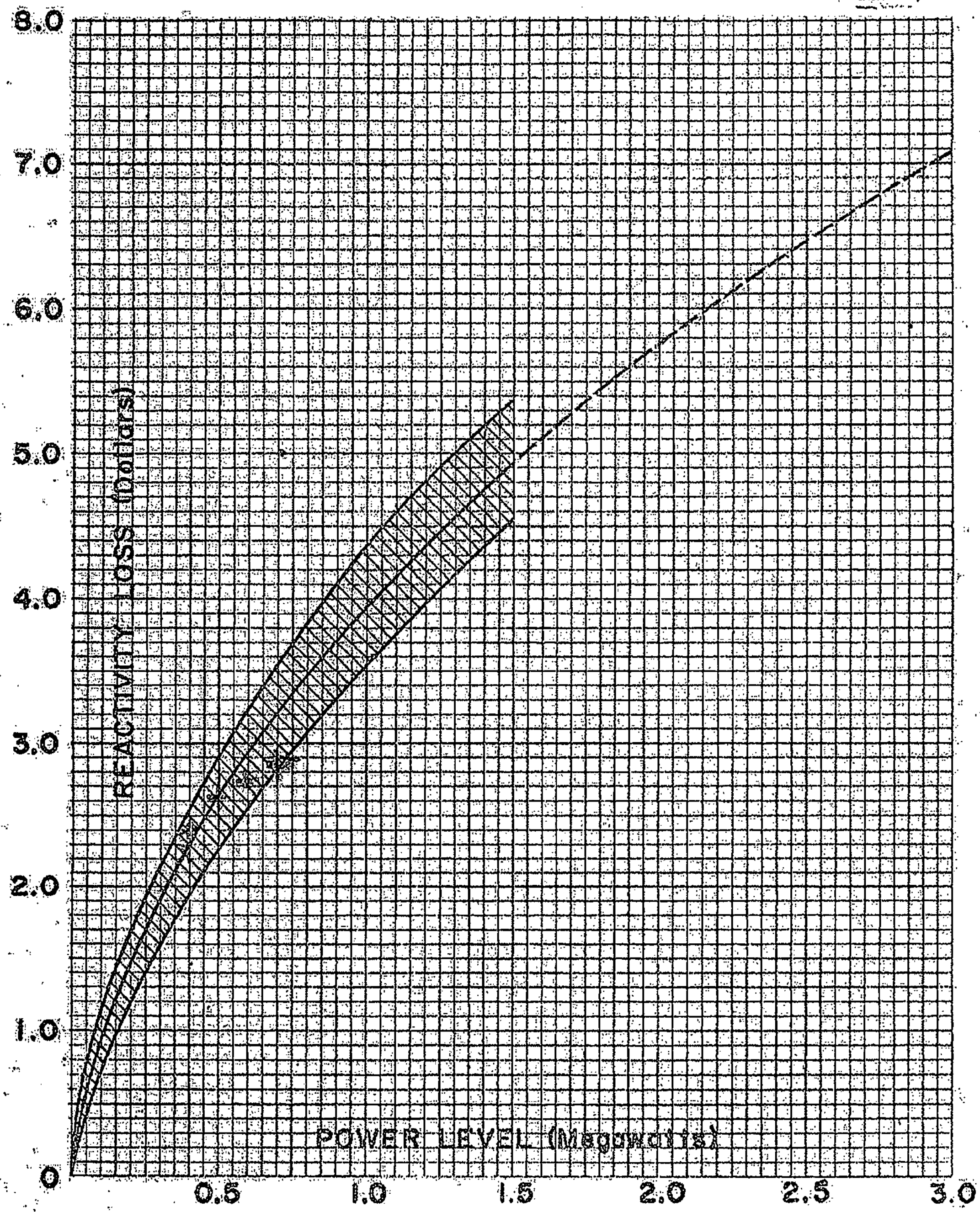
REACTIVITY LOSS

III-28

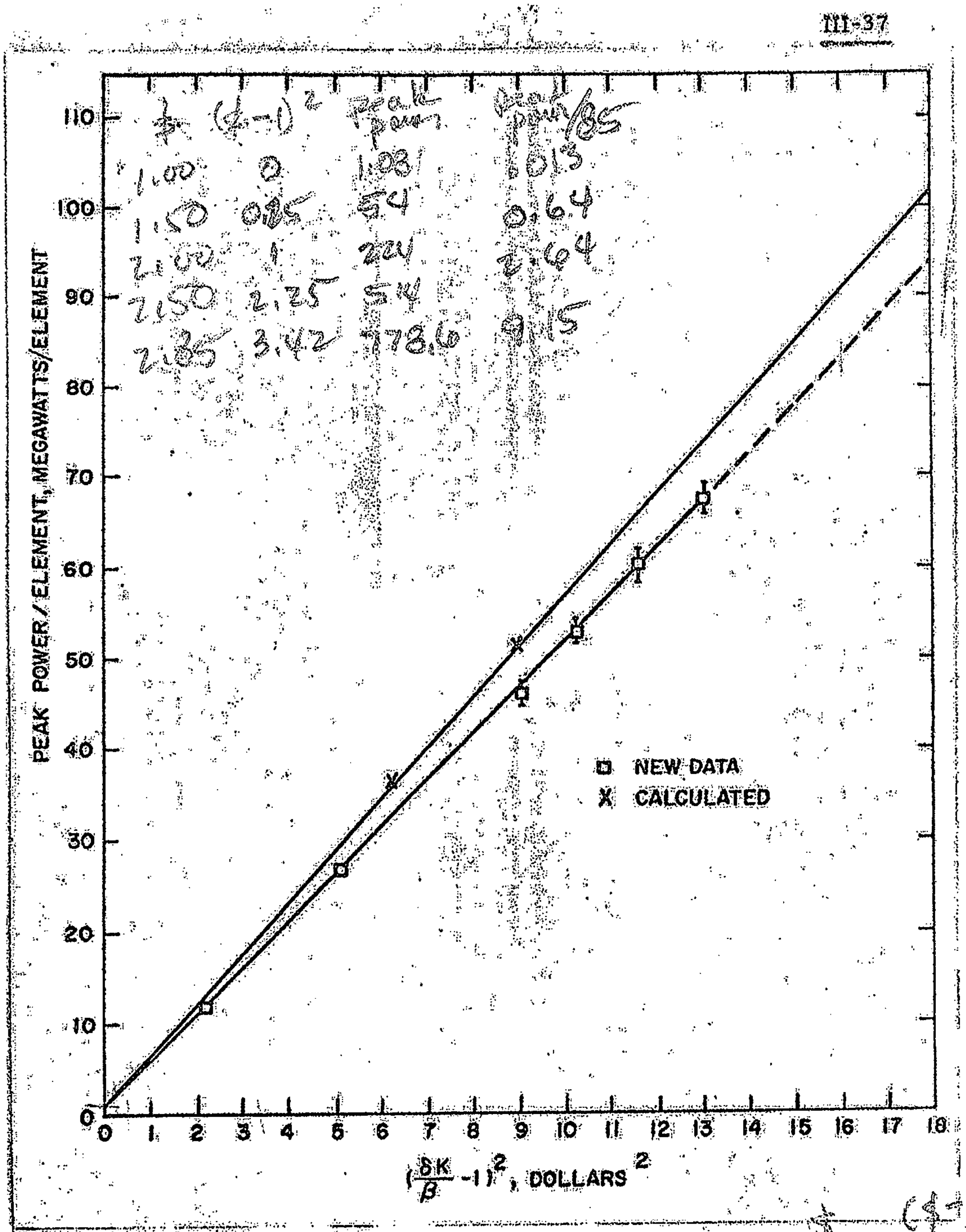



REACTOR POWER
Vs.
MAXIMUM and AVERAGE FUEL TEMPERATURE

III-29




REACTOR POWER
Vs.
REACTIVITY LOSS

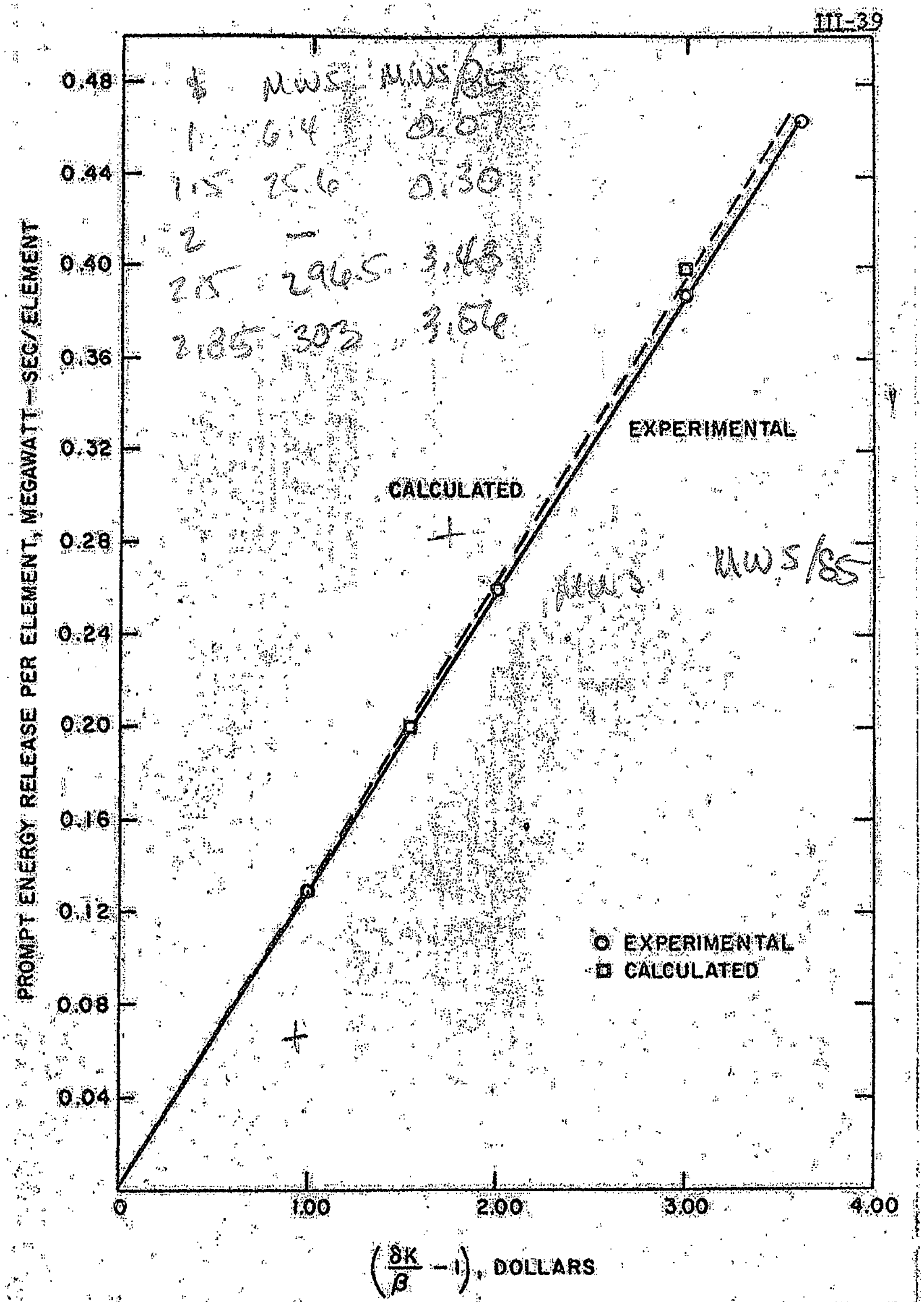



PEAK POWER/FUEL ELEMENT

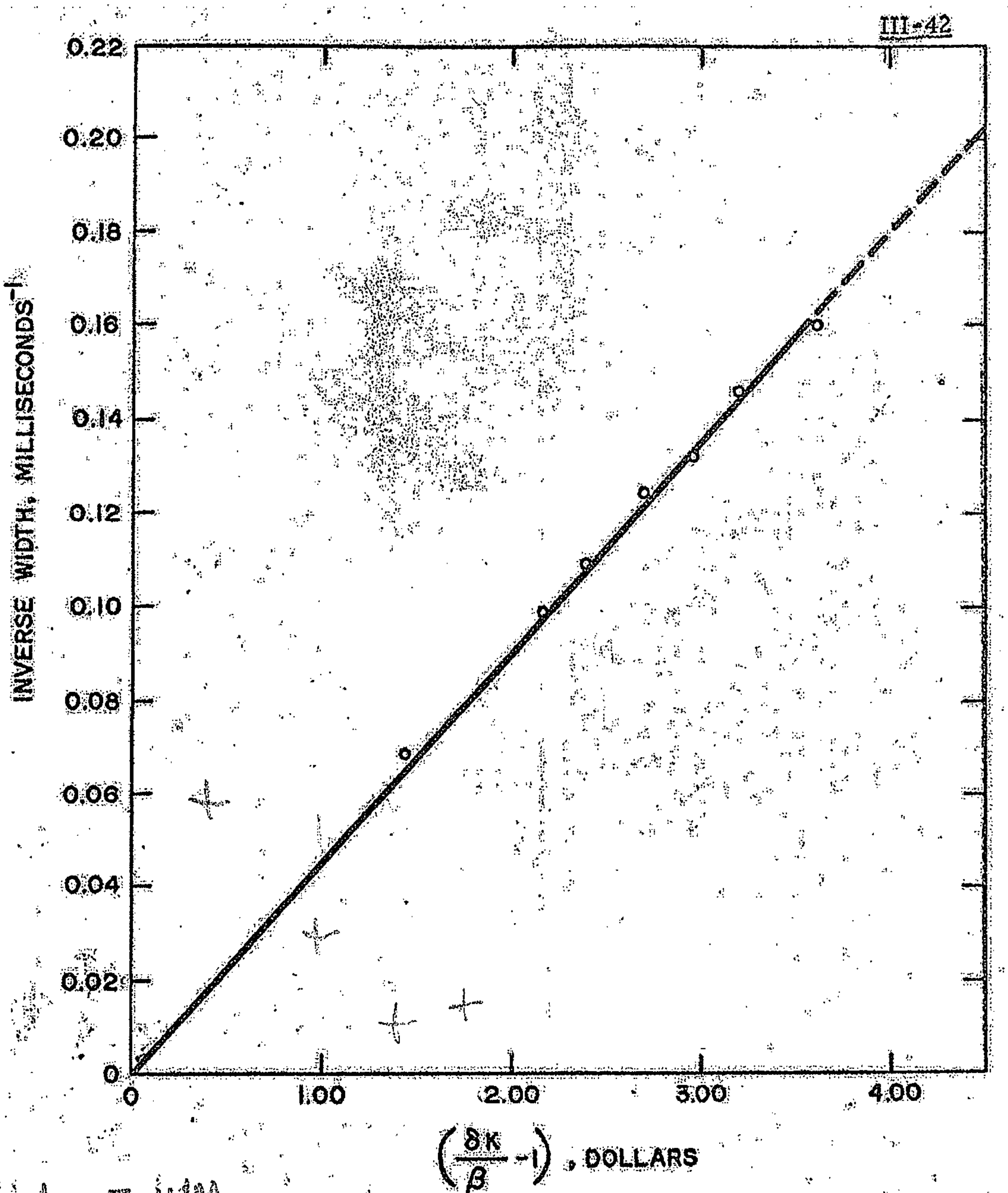
Vs.

REACTIVITY INSERTION

$ → ($-1)$^2$
1.00 → 0
1.50 → .25
2.00 → 1
2.50 → 2.25
2.85 → 3.42




PROMPT ENERGY RELEASE Vs. REACTIVITY INSERTION

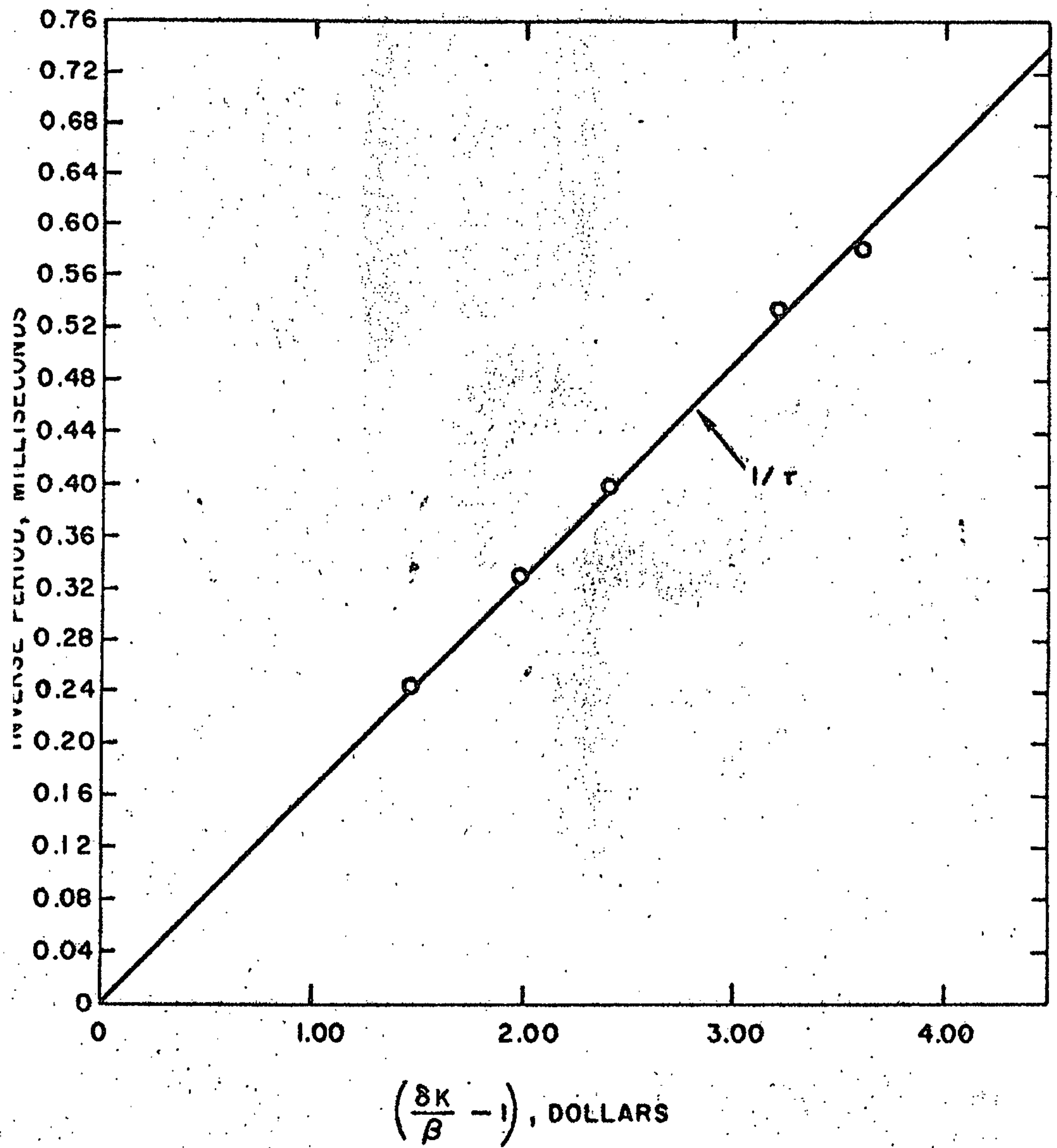



RECIPROCAL WIDTH

Vs.

REACTIVITY INSERTION

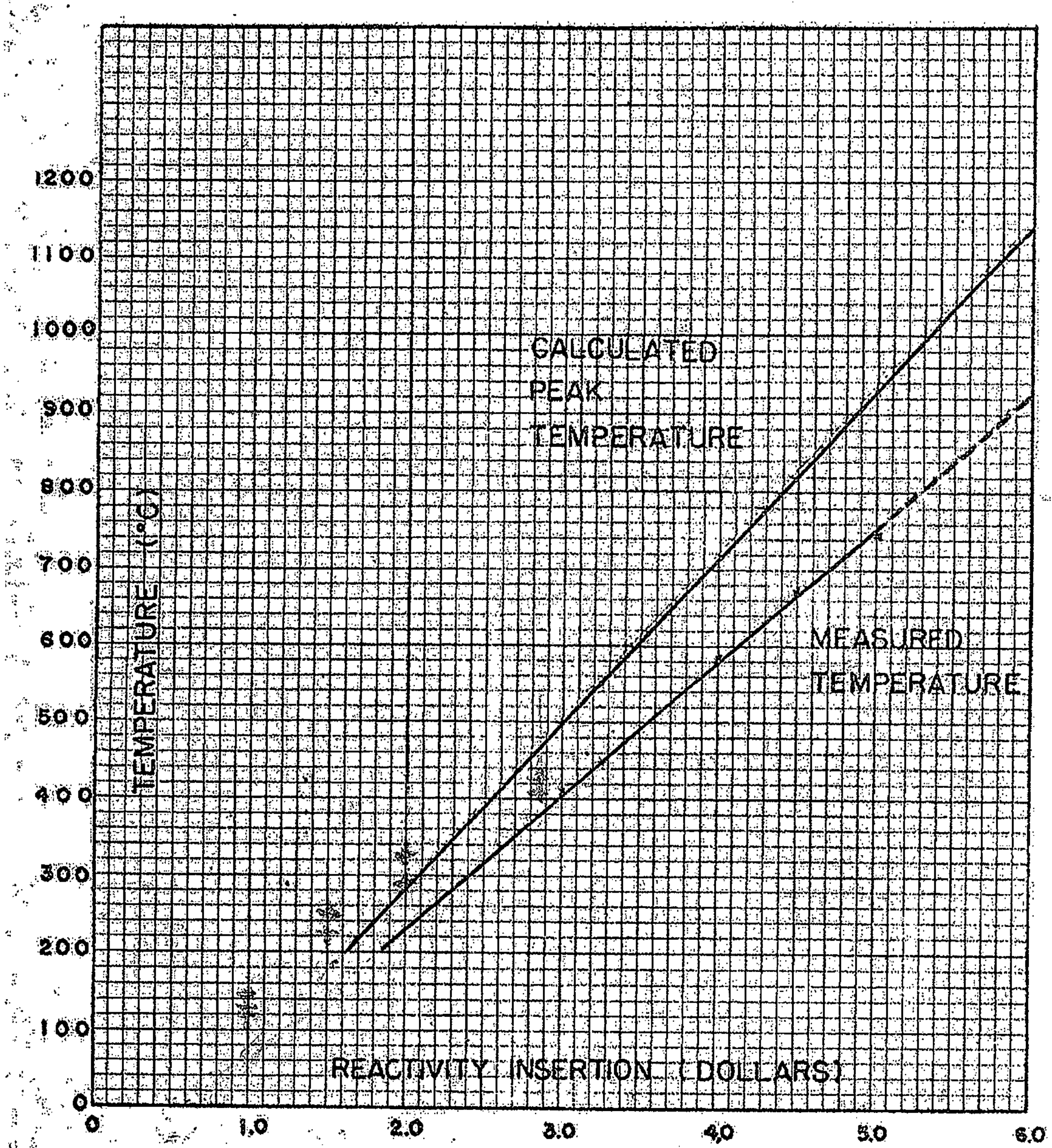
| $ | $-1 | FWHM |
|---|---|---|
| 1 | 0 | .0076 |
| 1.5 | .5 | .061 |
| 2 | 1 | .030 |
| 2.5 | 1.5 | .015 |
| 2.85 | 1.85 | .013 |




**INVERSE PERIOD**

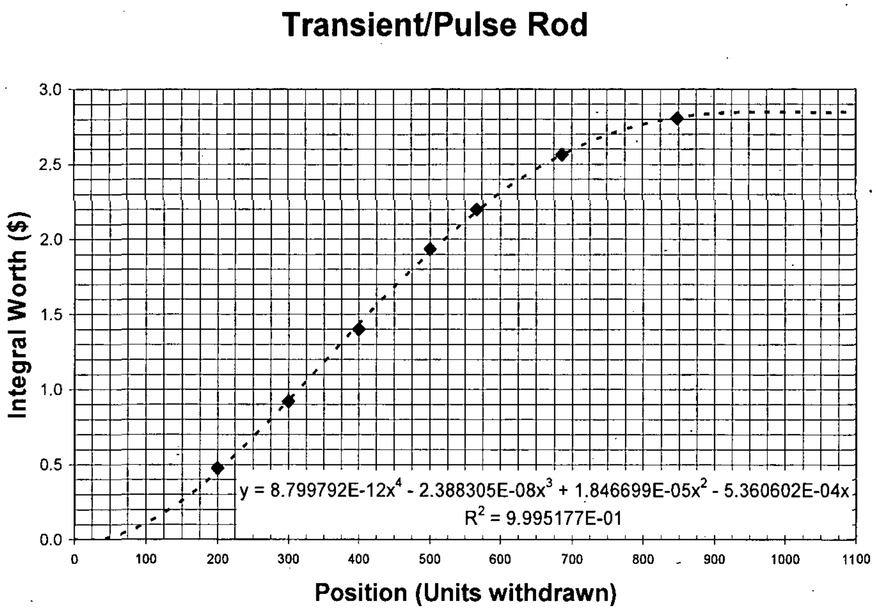
**Vs.**

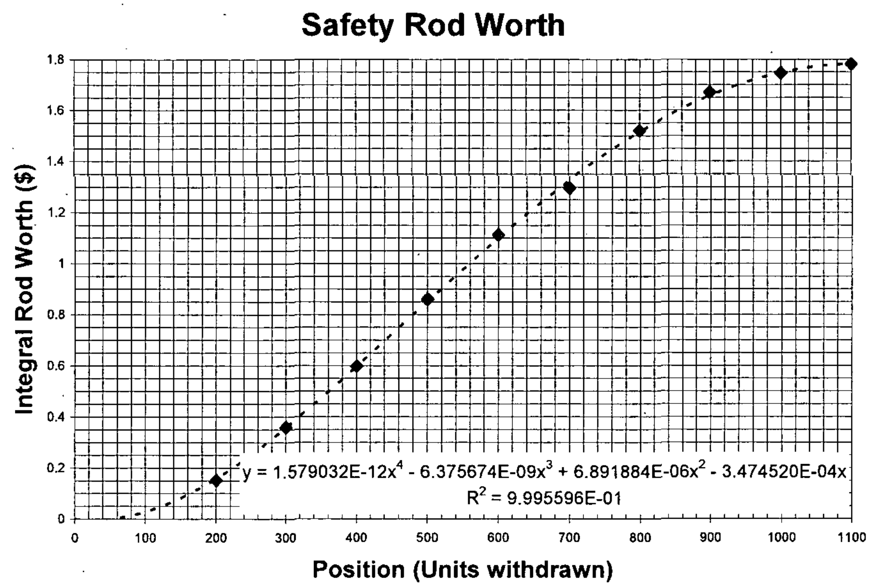
**REACTIVITY INSERTION**

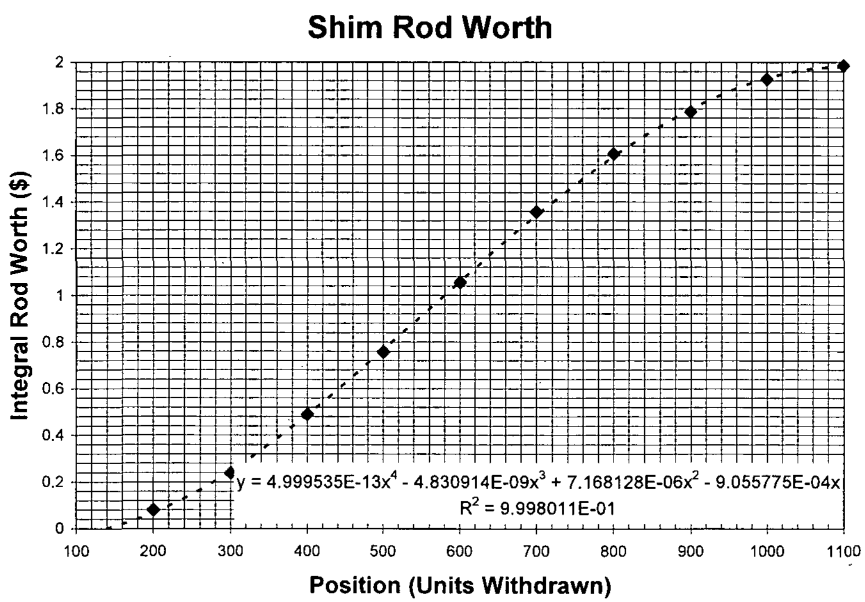


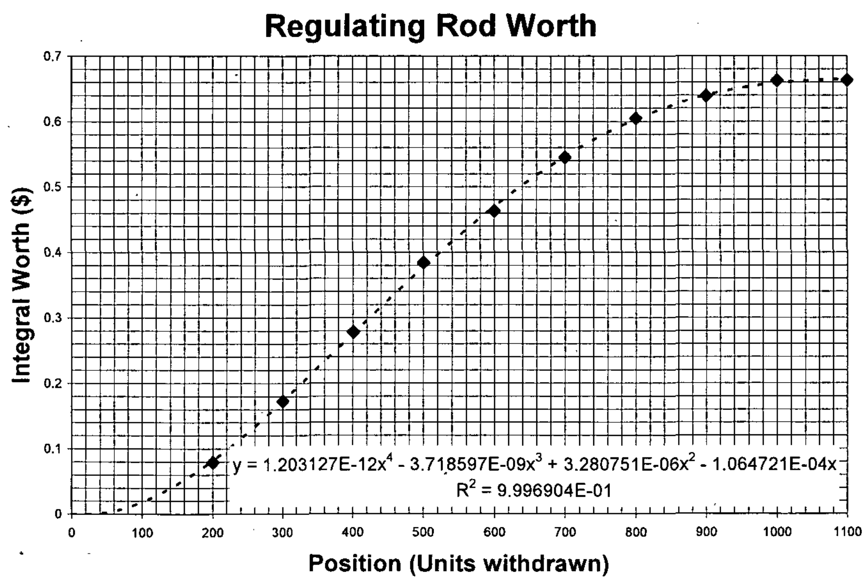

TEMPERATURE Vs. REACTIVITY INSERTION

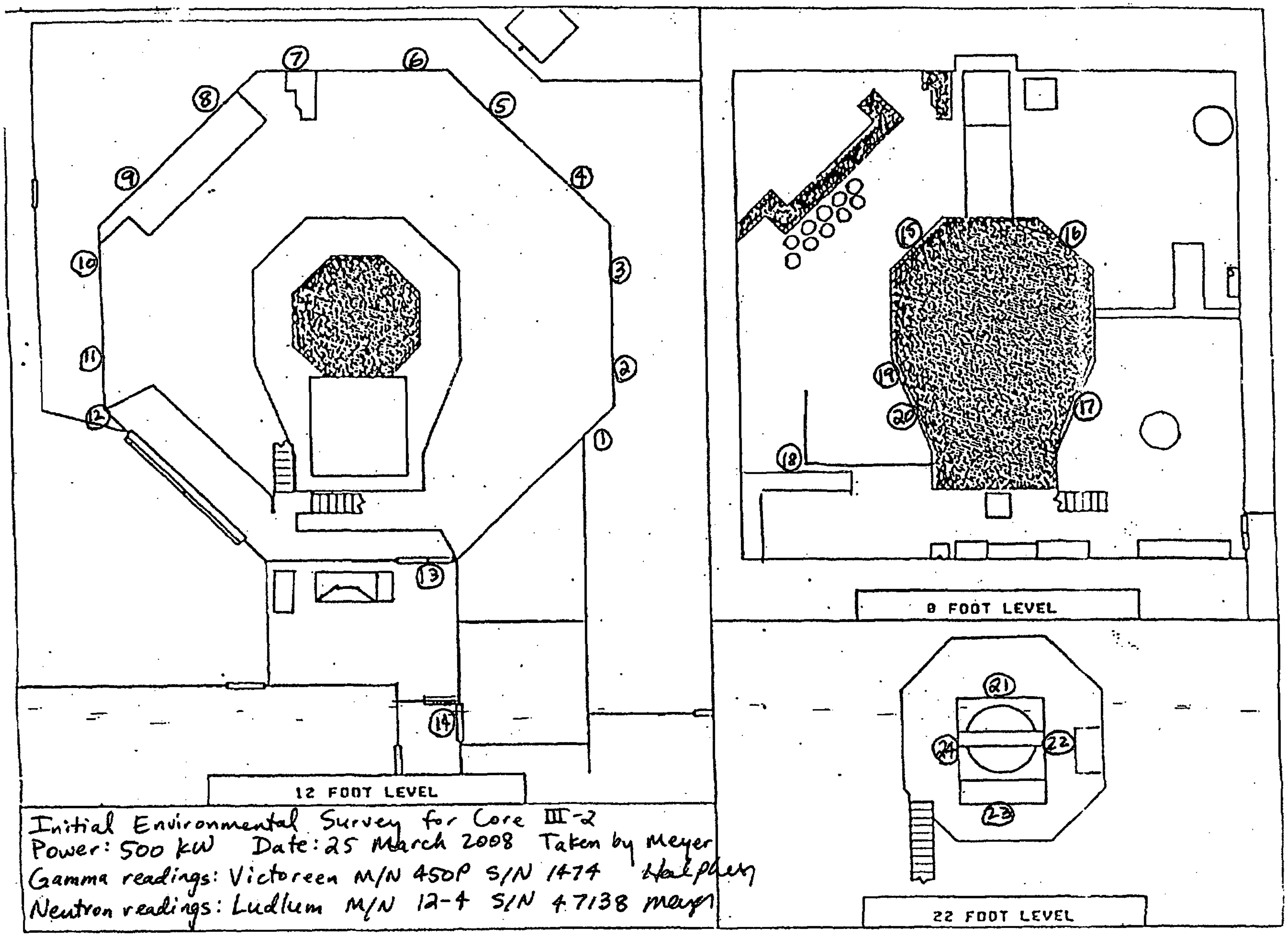
*Attachment II: Control Rod Calibration*

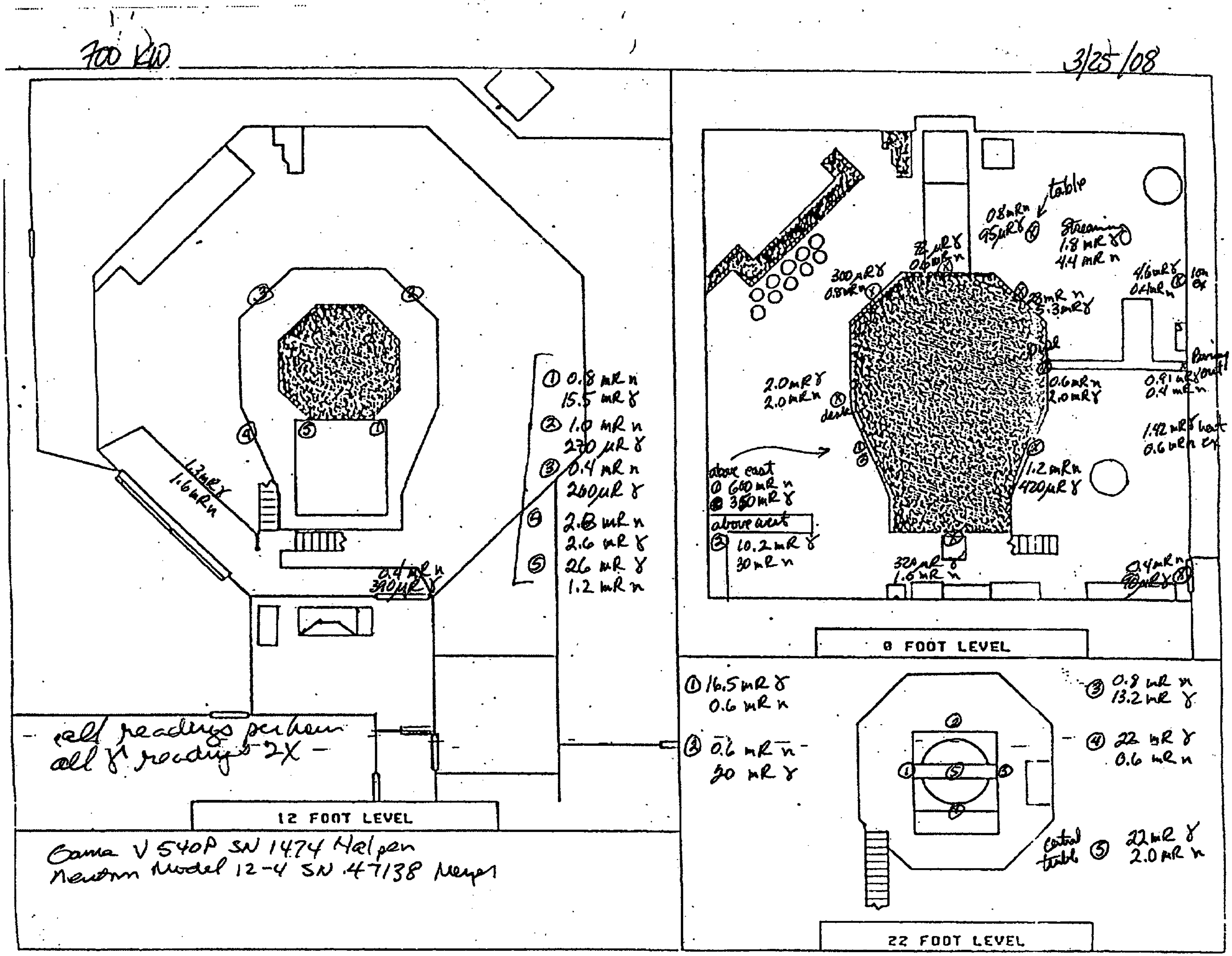


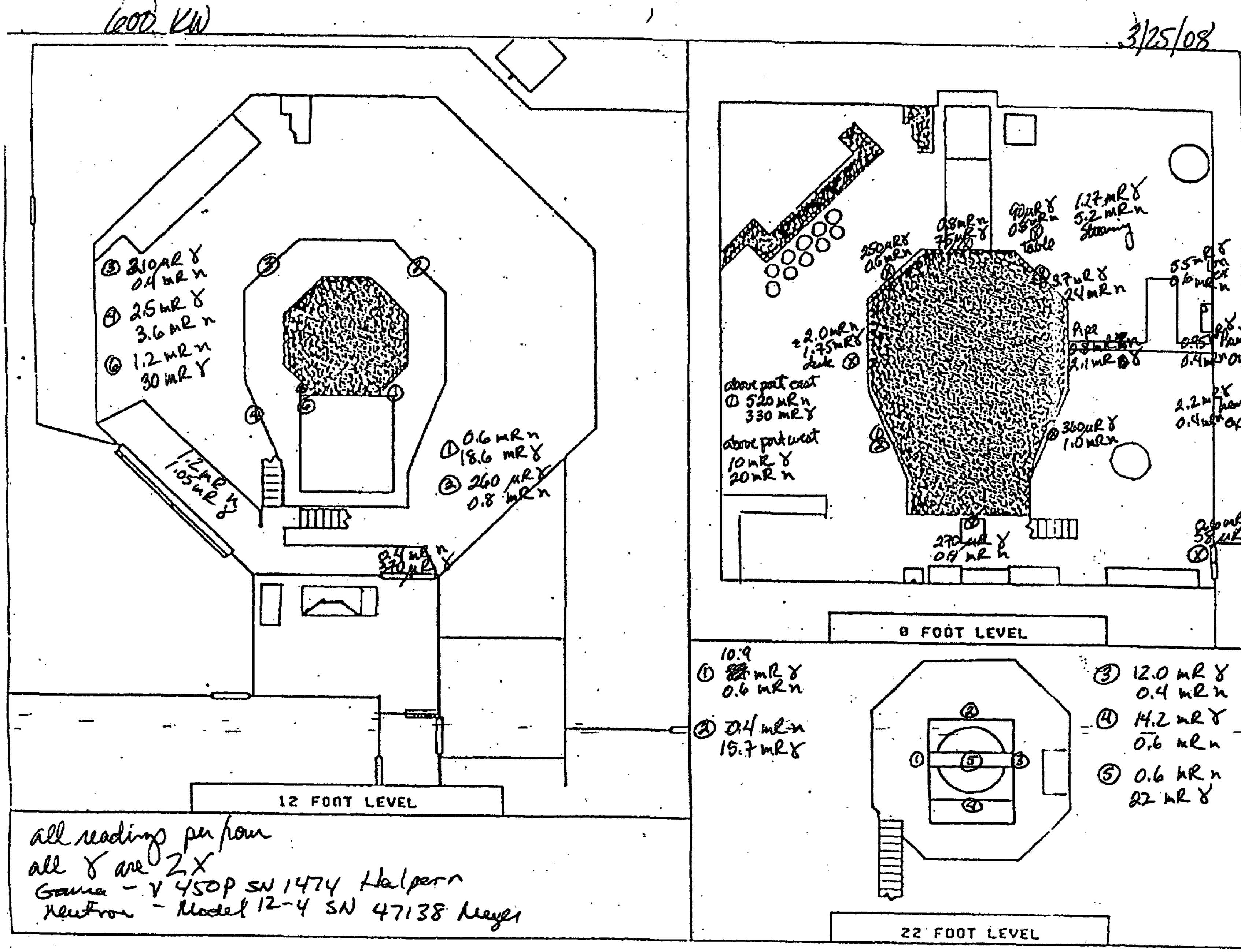



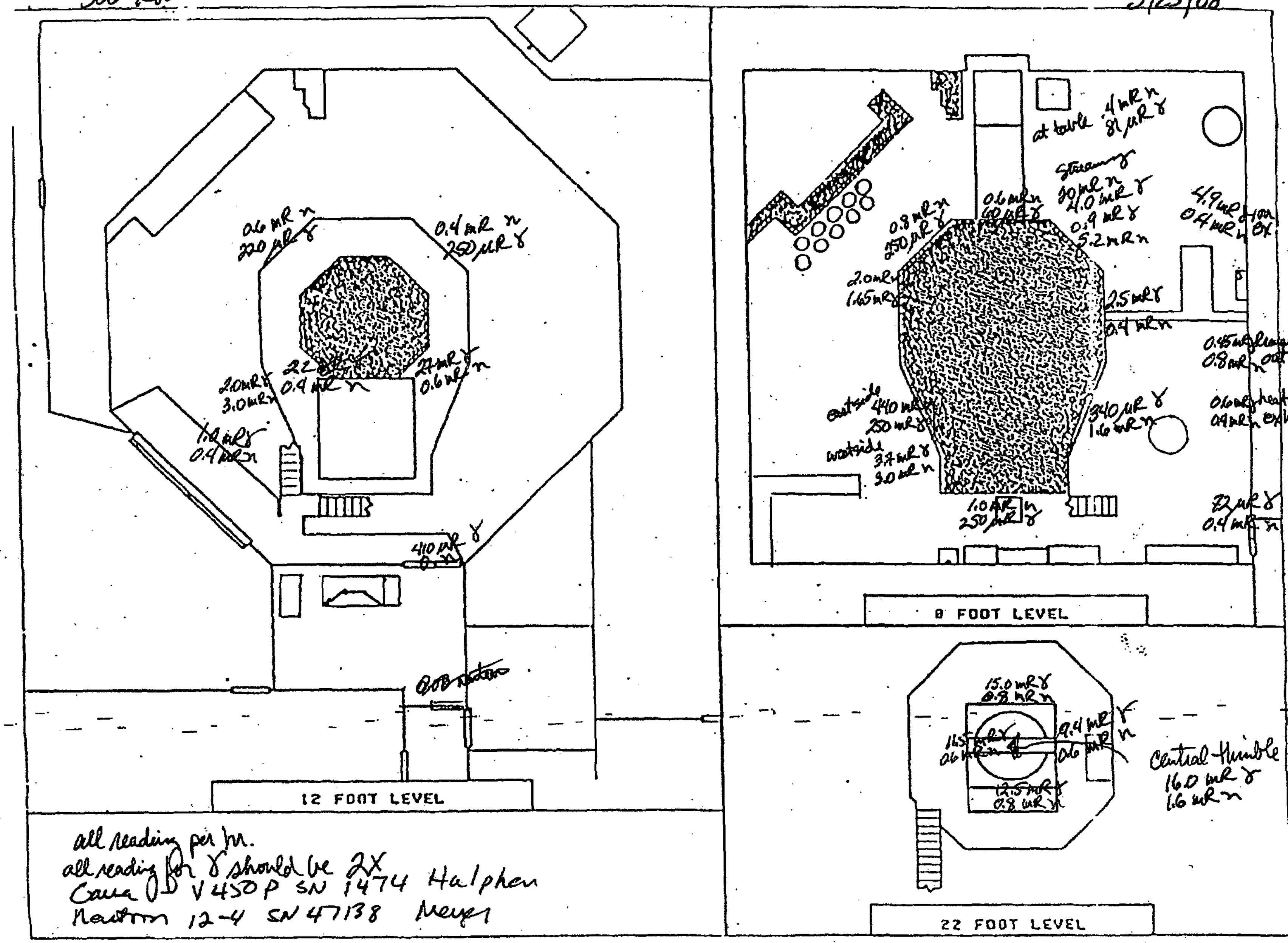



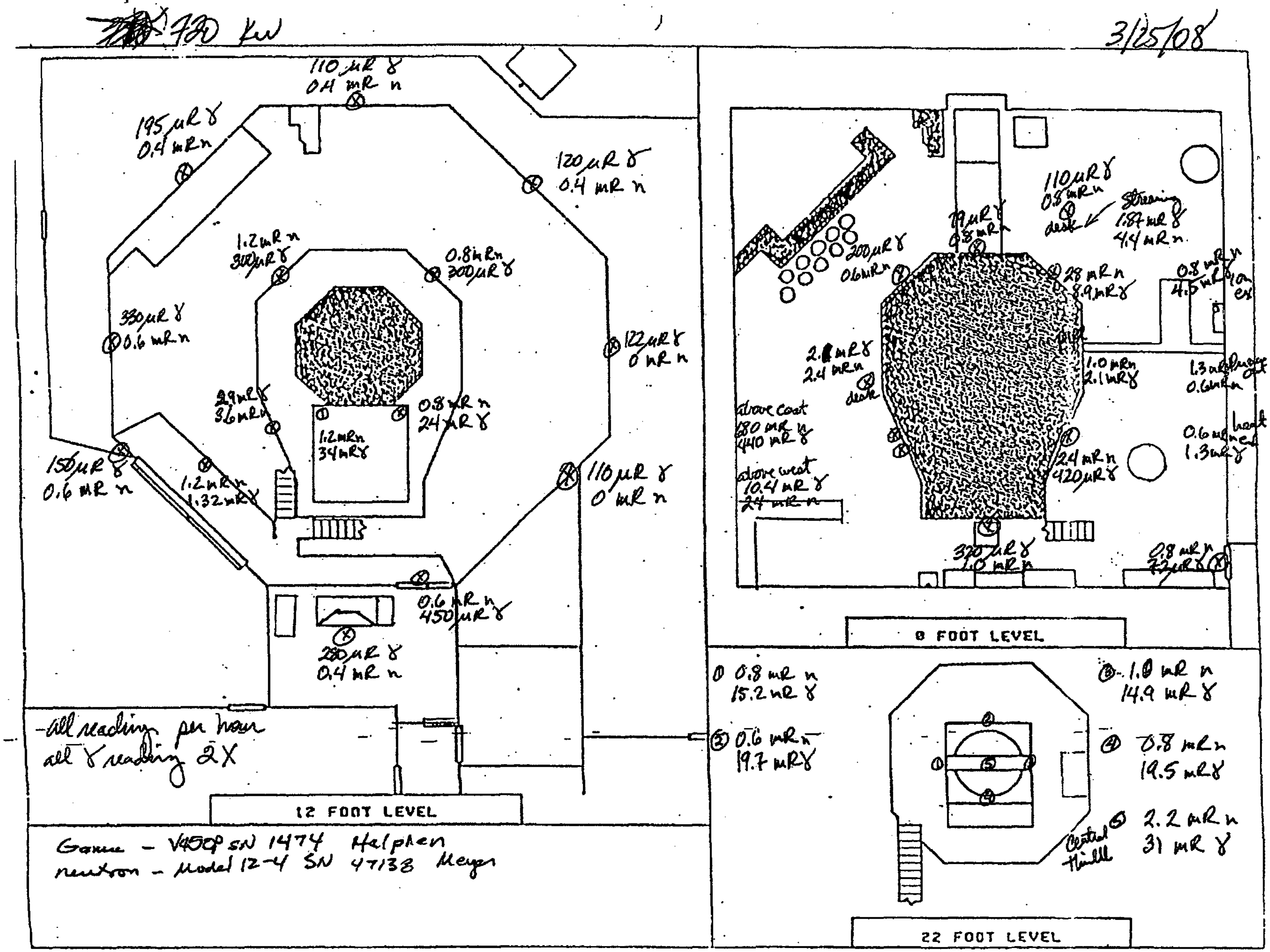

12 FOOT LEVEL
8 FOOT LEVEL
22 FOOT LEVEL
Initial Environmental Survey for Core III-2
Power: 500 kW Date: 25 March 2008 Taken by Meyer
Gamma readings: Victoreen M/N 450P S/N 1474 Halphen
Neutron readings: Ludlum M/N 12-4 S/N 47138 Meyer


700 KW
3/25/08
12 FOOT LEVEL
8 FOOT LEVEL
22 FOOT LEVEL
① 0.8 mR n 15.5 mR γ
② 1.0 mR n 270 μR γ
③ 0.4 mR n 200 μR γ
④ 2.8 mR n 2.6 mR γ
⑤ 26 mR γ 1.2 mR n
all readings per hour
all γ readings 2X
Gama V 540P SN 1474 Halpen
Neutron Model 12-4 SN 47138 Meyer
table
Streaming 1.8 mR γ 4.4 mR n
above east
above west
10.2 mR γ 30 mR n
① 16.5 mR γ 0.6 mR n
② 0.6 mR n 20 mR γ
③ 0.8 mR n 13.2 mR γ
④ 22 mR γ 0.6 mR n
central table ⑤ 22 mR γ 2.0 mR n


600 KW
3/25/08
12 FOOT LEVEL
8 FOOT LEVEL
22 FOOT LEVEL
③ 210 mR γ 0.4 mR n
④ 2.5 mR γ 3.6 mR n
⑥ 1.2 mR n 30 mR γ
① 0.6 mR n 18.6 mR γ
② 260 mR γ 0.8 mR n
1.2 mR n 1.05 mR γ
above port east ① 520 mR n 330 mR γ
above port west 10 mR γ 20 mR n
360 mR γ 1.0 mR n
270 mR γ 0.8 mR n
① 10.9 mR γ 0.6 mR n
② 0.4 mR n 15.7 mR γ
③ 12.0 mR γ 0.4 mR n
④ 14.2 mR γ 0.6 mR n
⑤ 0.6 mR n 22 mR γ
all readings per hour
all γ are 2X
Gamma - V 450P SN 1474 Halpern
Neutron - Model 12-4 SN 47138 Meyer

500 KW 3/25/08


12 FOOT LEVEL
8 FOOT LEVEL
22 FOOT LEVEL
0.6 mR n
220 μR γ
0.4 mR n
250 μR γ
2.0 mR γ
3.0 mR n
0.9 mR n
27 mR γ
0.6 mR n
1.0 mR γ
0.4 mR n
410 mR γ
at table .4 mR n
81 μR γ
0.8 mR n
250 μR γ
0.6 mR n
2.0 mR n
1.65 mR γ
2.5 mR γ
0.4 mR n
outside 440 mR γ
250 mR γ
340 mR γ
1.6 mR n
3.7 mR γ
3.0 mR n
1.0 mR n
250 μR γ
22 mR γ
0.4 mR n
15.0 mR γ
0.8 mR n
9.4 mR γ
0.6 mR n
12.5 mR γ
0.8 mR γ
Central thimble
16.0 mR γ
1.6 mR n
all reading per hr.
all reading for γ should be 2X
V450P SN 1474 Halphen
12-4 SN 47138 Meyer


720 kW
3/25/08
110 μR γ 0.4 mR n
195 μR γ 0.4 mR n
120 μR γ 0.4 mR n
1.2 mR n 300 μR γ
0.8 mR n 300 μR γ
330 μR γ 0.6 mR n
122 μR γ 0 mR n
2.9 mR γ 3.6 mR n
0.8 mR n 24 mR γ
1.2 mR n 34 mR γ
150 μR γ 0.6 mR n
1.2 mR n 1.32 mR γ
110 μR γ 0 mR n
0.6 mR n 450 μR γ
280 μR γ 0.4 mR n
-All reading per hour
all γ reading 2X
12 FOOT LEVEL
Gamma - V450P SN 1474 Helphen
neutron - Model 12-4 SN 47138 Meyer
110 μR γ 0.8 mR n
desk
Streaming 1.87 mR γ 4.4 mR n
19 mR γ 9.8 mR n
200 μR γ 0.6 mR n
28 mR n 8.9 mR γ
0.8 mR n 4.5 mR γ
2.8 mR γ 2.4 mR n
desk
1.0 mR n 2.1 mR γ
above coat 180 mR γ 440 mR n
24 mR n 420 mR γ
0.6 mR n 1.3 mR γ
above west 10.4 mR γ 24 mR n
320 mR γ 1.0 mR n
0.8 mR n 7.2 mR γ
0 FOOT LEVEL
① 0.8 mR n 15.2 mR γ
② 1.0 mR n 14.9 mR γ
③ 0.6 mR n 19.7 mR γ
④ 0.8 mR n 19.5 mR γ
⑤ 2.2 mR n 31 mR γ
Central Thimble
22 FOOT LEVEL

## Measurements for Initial Environmental Surveillance for Core III-2

Power: 500 kW
Date: 25 March 2008
Taken by Meyer
Gamma readings: Victoreen M/N 450P S/N 1474
Neutron readings: Ludlum M/N 12-4 S/N 47138

| Site | Gamma (mR/h) | Neutron (mrem/h) | Description of Site |
|---|---|---|---|
| 1 | 0.168 | 0.4 | Window |
| 2 | 0.190 | 0.4 | Window |
| 3 | 0.216 | 0.4 | Window |
| 4 | 0.218 | 0.4 | Window |
| 5 | 0.290 | 0.4 | Window |
| 6 | 0.212 | 0.4 | Window |
| 7 | 0.248 | 0.4 | Window |
| 8 | 0.278 | 0.4 | Window |
| 9 | 0.388 | 0.4 | Window |
| 10 | 0.420 | 0.8 | Window |
| 11 | 0.660 | 0.4 | Window |
| 12 | 0.260 | 0.6 | Window |
| 13 | 0.230 | 0.6 | Control Room Door |
| 14 | 0.134 | 0.6 | 0' Level Door |
| 15 | 0.420 | 0.8 | NEBP Door (secured) |
| 16 | 8.8 | 4.0 | SEBP Shutter (closed) |
| 17 | 0.780 | 1.0 | SWBP Door (secured) |
| 18 | 0.620 | 1.0 | NWBP Fence corner |
| 19 | 9.0 | 8.0 | NWBP Side (M-V configuration |
| 20 | 214 | 300 | NWBP Above (M-V configuration) |
| 21 | 26.0 | 0.6 | East Railing |
| 22 | 20.0 | 0.6 | South Railing |
| 23 | 22.6 | 0.6 | West Railing |
| 24 | 23.4 | 1.0 | North Railing |