The Effect of an Installed Neutron Source on Positive Period Differential Control Rod Worth Measurements

Jeffrey A. Geuther, Jesse L. Chadwick, Tyrel D. F. George, David A. Heitmeyer, Chris M. Robins, Neal R. Strathman

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Introduction

- In 2010, an operator at the KSU reactor received a higher than necessary dose during an experiment due, in part, to an inadequate written procedure
- Over the following year, many procedures were amended, and as a result the person-rem of dose to the staff was reduced by a factor of five.
- However, only safety issues were addressed – some procedures have been used without amendment for 20+ years.

Introduction

- The control rod calibration procedure had gone since 1992 without a revision, but had several "pen and ink" changes in the text.
- Among these changes – advice to pull the AmBe startup source prior to performing positive period measurements.
- The concern is that, while often ignored in calculations, the installed source does affect the time behavior of the reactor, and there is a difference between "critical" and "source critical."
  - Addition of source neutrons can change perceived doubling time / period in stopwatch measurements

Introduction

- Note:
  - The KSU TRIGA uses boron and carbon cylindrical control rods
  - The rods are 1.125" – 1.25" in diameter
  - Rods are spaced ~20 cm apart
  - In order to minimize the effect of rod shadowing on the comparison of source in / source out measurements, the same control rod positions were used to achieve criticality in both cases.

Introduction

- It makes sense that source can be ignored if $q \ll N$
- The KSU TRIGA uses an AmBe source with $q \approx$ 2.2E6 n / s
- Positive period measurements are started at 10 W:

$$N = 10\text{ W} \cdot \frac{1\text{ eV / s}}{1.6\times10^{-19}\text{ W}} \cdot \frac{1\text{ fission}}{2\times10^{8}\text{ eV}} \cdot \frac{2.43\text{ neutrons}}{\text{fission}}$$

$$N = 7.6\times10^{11}\text{ neutrons / second}$$

- The procedural guidance seems unnecessary
  - AmBe source emits ~2 x 10^6 n /sec
  - Fission source in core at 10 W is ~10^{11} – 10^{12} n / sec

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Introduction

- We sought to determine whether it should be permissible to perform the experiment with the source installed using two methods:
  - The experiment was performed with an without an installed source.
  - A MATLAB script was written to plot the power based on the six group approximation to the PRKE, with varying values of the source strength *q*.

$$\frac{dN}{dt} = \left(\frac{\rho - \beta}{\Lambda}\right)N + \sum_{i=1..6} \lambda_i C_i + q$$

$$\frac{dC_i}{dt} = \left(\frac{\beta_i}{\Lambda}\right)N - \lambda_i C_i \qquad i = 1..6$$

Methodology - Measurement

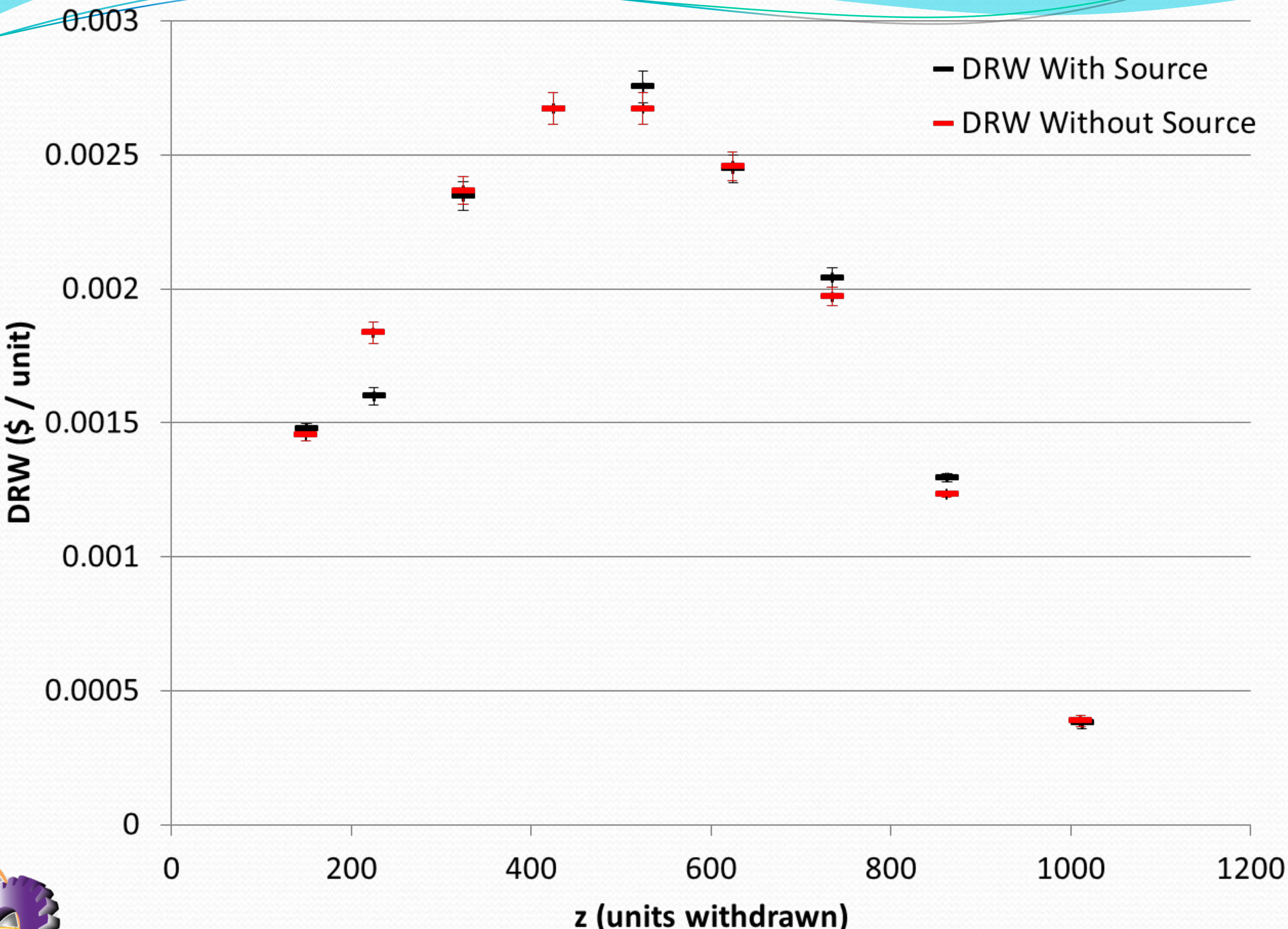
- Methodology for measured IRW:
  - Raise reactor power to 1 W, critical with or without source
  - Withdraw test rod until stable period is ~60 – 80 s
  - Allow power to increase through 1 decade to reach stable period
  - Measure reactor doubling time
  - Use doubling time to determine ρ by table lookup
  - Calculate DRW and IRW:

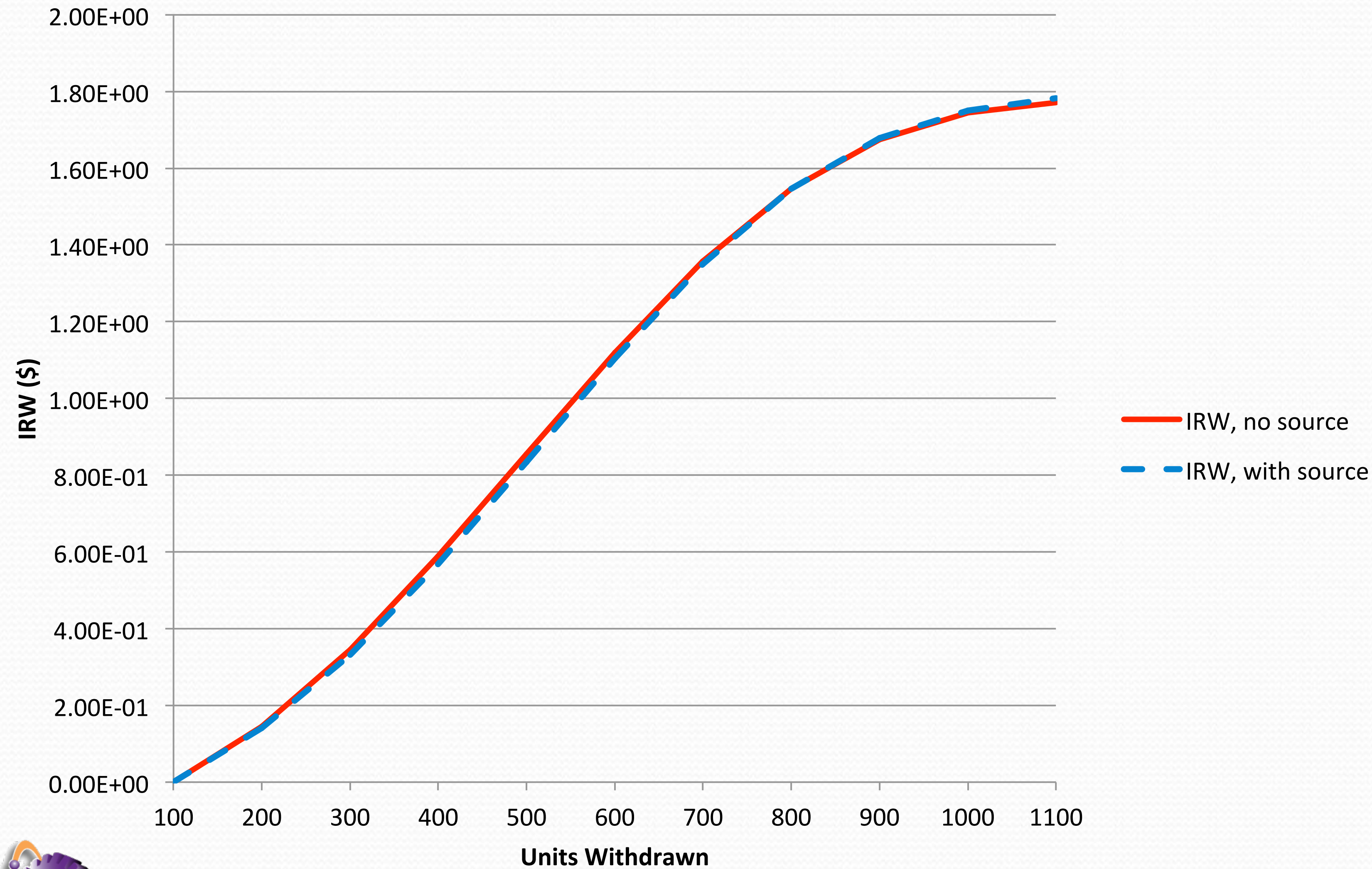
$$DRW(z) = \frac{\Delta\rho}{\Delta z}$$

$$IRW(z) = \int_{z_0}^{z} DRW(z')dz'$$

Methodology - Measurement

- The procedure also allows for a rod drop IRW measurement.
- Positive period method is preferred:
  - Average operator spends 1 – 2 years at facility after receiving license
  - Positive period method is a more “hands-on” technique
  - It is easier for the student operators to understand the connection between the period and reactivity than from post-rod drop power level


0.003
0.0025
0.002
0.0015
0.001
0.0005
0
DRW ($ / unit)
0
200
400
600
800
1000
1200
z (units withdrawn)
DRW With Source
DRW Without Source


2.00E+00
1.80E+00
1.60E+00
1.40E+00
1.20E+00
1.00E+00
8.00E-01
6.00E-01
4.00E-01
2.00E-01
0.00E+00
IRW ($)
100
200
300
400
500
600
700
800
900
1000
1100
Units Withdrawn
IRW, no source
IRW, with source

Results – Measured IRW

- Maximum difference between measured IRW was 4% (due to DRW outlier at z ≈ 250)
- Total IRW values agreed within 0.01$ (~0.5%)
- Evidence for the presence of the startup source being irrelevant to final measured value.

Methodology – Calculated Reactivity

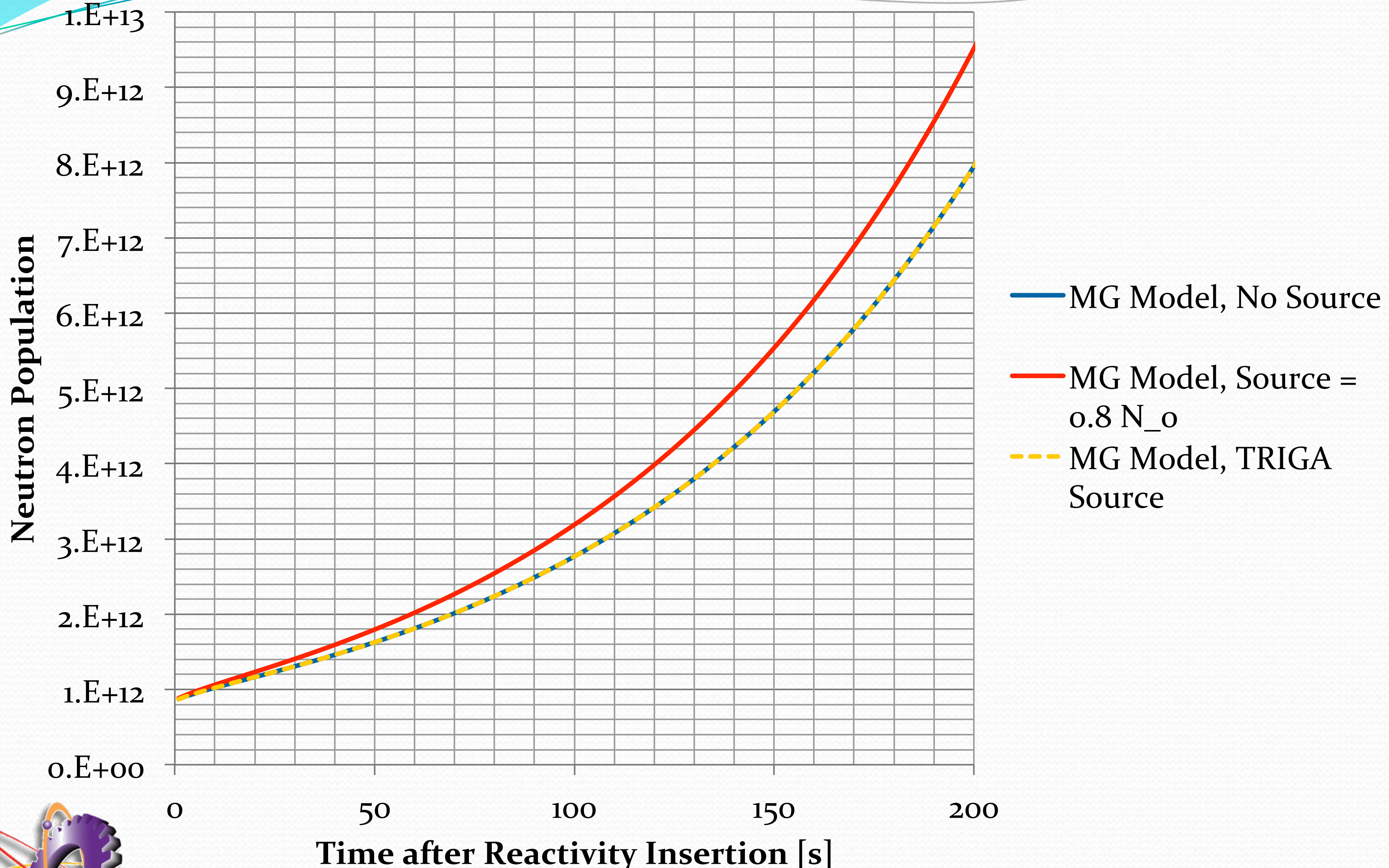
- MATLAB script was programmed with 6-group PRKE
- Source term was varied from 0 neutrons per second to 0.8 * fission source term at starting power (10 W)
- DRW measurement was simulated:
  - Reactivity was perturbed by 0.10$
  - After 1 decade power increase, doubling time was calculated based on calculated power trend
  - Table lookup was used to determine ρ based on doubling time

Methodology – Calculated Reactivity

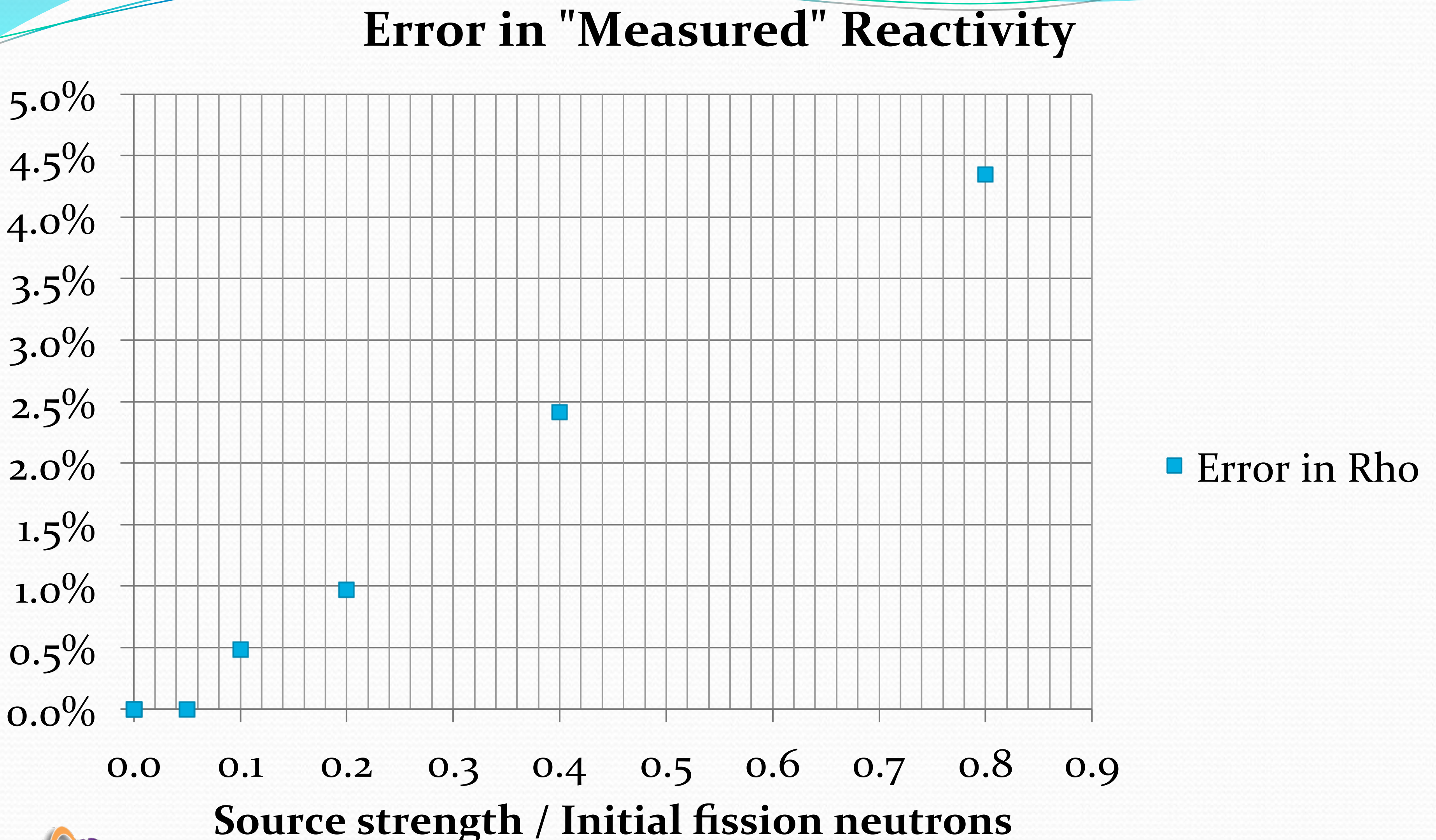
- Error in calculated reactivity due to source term was calculated by:

$$\varepsilon = \frac{\rho' - \rho}{\rho}$$

- It was determined that the measurements would only be sensitive to the source if $q > 0.1\, n_0$



1.E+13
9.E+12
8.E+12
7.E+12
6.E+12
5.E+12
4.E+12
3.E+12
2.E+12
1.E+12
0.E+00
Neutron Population
0
50
100
150
200
Time after Reactivity Insertion [s]
MG Model, No Source
MG Model, Source = 0.8 N_0
MG Model, TRIGA Source



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Conclusions

- For KSU TRIGA, q = 2.9E-6 n_o
- MATLAB script indicates that the presence of the source should not affect measured DRW or IRW
- This expectation has been confirmed by a measurement of IRW with and without installed source
- For a source strength in excess of 10% of n_o, care should be taken with regard to whether source is installed.

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