Recent LANL/CEA Valduc Neutron Measurements

J. Hutchinson, A. Sood, M. Smith-Nelson, J. Goda, J. Bounds, W. Myers, T. Cutler, B. Richard, B. Rooney, D. Hayes, R. Sanchez
Los Alamos National Laboratory

A. Chapelle, P. Casoli, N. Authier
Commissariat `a l'Energie Atomique et aux Energies Alternatives (CEA) Valduc

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Background

- Discussions began for a CEA/LANL collaboration to perform subcritical measurements at Valduc at a Subcritical Measurement Workshop in July 2011 at LANL.
- Several goals for measurements:
  - CEA research of neutron noise measurements (thesis work of Amaury Chapelle).
  - Validation of US work on subcritical experiments:
    - New simulation methods (MCNP list-mode patch)
    - New detector hardware
    - New analysis software
  - Provide additional measurements to compare Caliban and Godiva-IV.
  - Continue US/French collaboration on integral experiments.

Background

- Original proposal included 4 Caliban configurations: Safety Block (SB) out, SB fully inserted, and SB at two intermediate configurations.
- Two measurement campaigns were performed:
  - Valduc, June 2012: Caliban
  - NCERC, July 2013: Godiva-IV, Planet (class foils), and Flat-Top
- Measured over 50 configurations between the 4 assemblies.
- This presentation will focus on the Caliban and Godiva-IV measurements.

Introduction

- Four “main” detector systems used: 2 LANL NPOD detectors, one LANL SNAP detector, and one CEA detector system with three He-3 tubes inside polyethylene.
- All detectors were run remotely (from the control rooms).

Team for Valduc Measurement Campaign: June 2012

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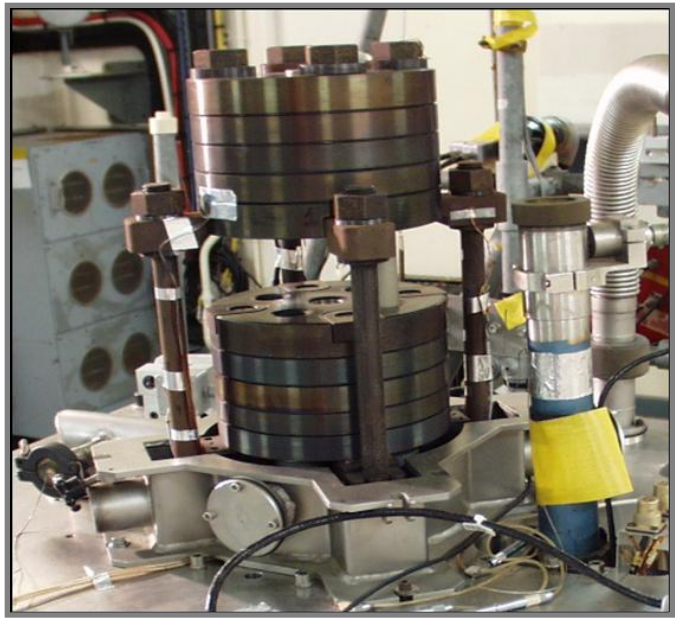
Team for NCERC Measurement Campaign: July 2013

Caliban Overview

- Metallic cylindrical core
  - ^{235}U and Mo alloy
  - Diameter = 19.5 cm
  - Height = 25 cm
  - 113 kg of HEU
- 2 blocks
  - A mobile one (below)
  - A fixed one (above)
- 4 control rods
  - Same composition as the blocks
- Cylindrical central irradiation channel



Godiva-IV Overview

- Cylindrical uranium metal fast burst assembly
- 65 kg, 93% enriched
- 7-inch diameter (17.8 cm), 6-inch tall (15.2 cm)
- Operates at delayed critical or prompt critical
- Maximum burst is approximately 90,000 MW_{th} with a full width half max (FWHM) pulse of 25 μs

Caliban Configurations

		Element Positions (in mm)			
Configuration		SB position	BC1	BC2	BC3
SB out	S1	0.089	0.000	0.000	0.000
SB 10mm	S2	9.970	0.000	0.000	0.000
SB 20mm	S3	20.019	0.000	0.000	0.000
SB 40mm	S4	40.019	0.000	0.000	0.000
SB 60mm	S5	60.009	0.000	0.000	0.000
SB 65mm	S6	65.032	0.000	0.000	0.000
SB 67.5mm	S7	67.501	0.000	0.000	0.000
SB in	S8	70.531	0.000	0.000	0.000
300 cent subcritical	S9	70.529	5.550	90.850	6.080
200 cent subcritical	S10	70.530	120.000	82.630	5.710
150 cent subcritical	S11	70.531	120.000	118.510	6.100
100 cent subcritical	S12	70.531	205.120	69.900	7.000
80 cent subcritical	S13	70.531	205.100	87.700	6.790
delayed critical	DC1	70.532	205.120	69.970	110.000
delayed critical	DC2	70.531	205.100	87.700	96.200
500 second period	PP1	70.532	205.100	50.000	127.590
60 second period	PP2	70.532	205.100	50.000	135.590

- 0 means element is fully withdrawn

Godiva-IV Configurations

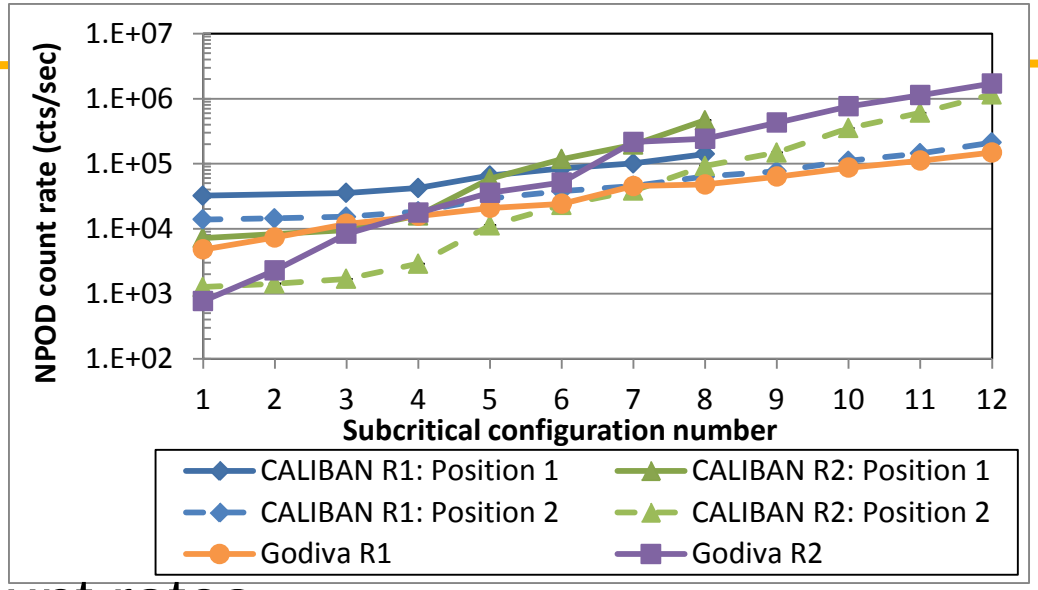
		Element Positions (in inches)		
Configuration		SB position	CR1	CR2
SB out	S1	7.844	4.050	4.050
SB 2.083"	S2	2.083	4.050	4.050
SB 0.994"	S3	0.994	4.050	4.050
SB 0.544"	S4	0.544	4.050	4.050
SB 0.272"	S5	0.272	4.050	4.050
SB 0.161"	S6	0.161	4.050	4.050
SB in	S7	-0.130	4.050	4.050
200 cents subcritical	S8	-0.130	3.606	3.504
150 cents subcritical	S9	-0.130	2.258	2.448
100 cents subcritical	S10	-0.130	1.706	1.655
75 cents subcritical	S11	-0.130	1.344	1.304
50 cents subcritical	S12	-0.130	1.048	1.000
Delayed critical	DC1	-0.130	0.312	0.311
Delayed critical	DC2	-0.130	0.363	0.364
Delayed critical	DC3	-0.130	0.158	0.151
500 sec period	PP1	-0.130	0.097	0.151
180 sec period	PP2	-0.130	0.097	0.057
120 sec period	PP3	-0.130	0.023	0.057

- 0 (or negative number) means element is fully inserted

Analysis method

- Data analyzed using “Momentum”
  - Hage-Cifarelli formulism used
  - Sequential binning
  - 512 gates of 4 micro-sec each
  - All data shown are asymptotic results (not using a particular gate width)
  - Nu-bar data used included Cf-252 starters and U-235 induced fission
- Total multiplication determined from leakage multiplication using the Serber equation (LA-335, 1945).

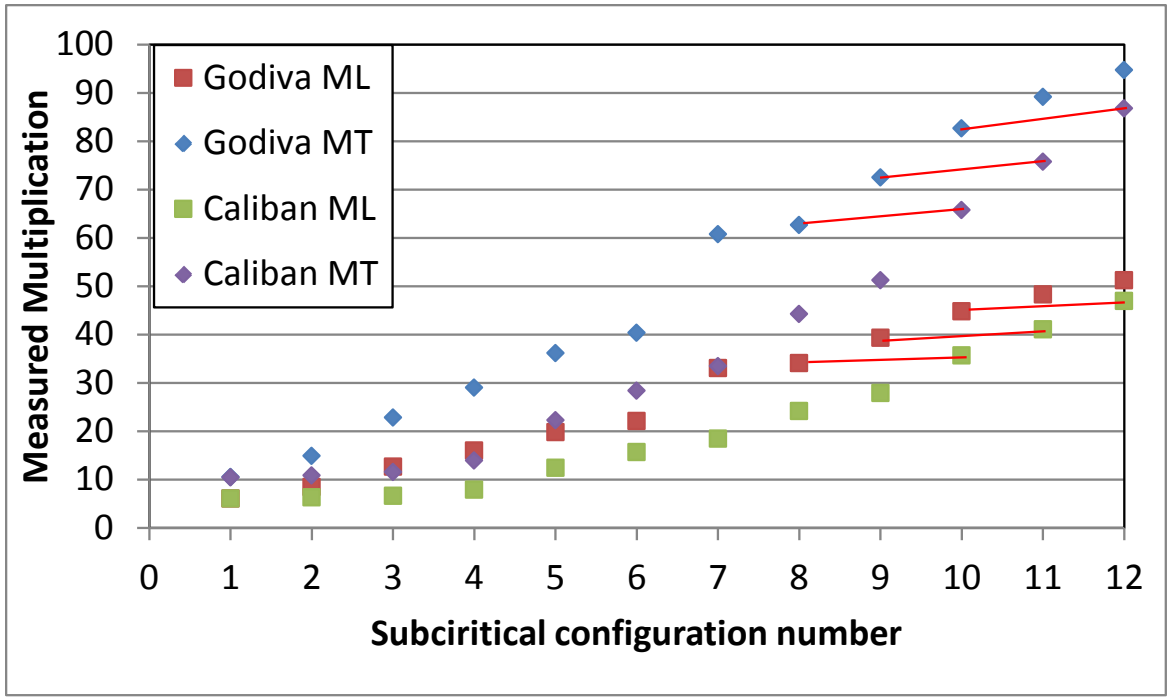
Results



- NPOD count rates
  - Caliban and Godiva count rates should not be directly compared since different sources, different multiplications, and different detector setups.
  - Only two things are important to note:
    - The count rates are always increasing as expected.
    - The count rates are very high.

Results

- Multiplication results.
- Lines drawn between configurations with equivalent reactivities.



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Results: Caliban

From CR worth curves

	Configuration	S8	S9	S10	S11	S12
Control rod worth curves	ρ/β ($)	-3.72	-3.00	-2.00	-1.50	-1.00
	ρ	-0.025	-0.020	-0.013	-0.010	-0.007
	k_{eff}	0.976	0.981	0.987	0.990	0.993
	k_p	0.970	0.974	0.980	0.984	0.987
	M_T	32.9	38.7	51.2	61.3	76.4
NPOD Feynman Analysis	M_T	44.2	51.2	65.7	75.7	86.7
	k_p	0.977	0.980	0.985	0.987	0.988
	k_{eff}	0.984	0.987	0.991	0.993	0.995
	C/E M_T	0.745	0.756	0.780	0.809	0.881
	C/E k	0.992	0.994	0.996	0.997	0.998
MCNP KCODE (bias adjusted)	k_{eff}	0.975	0.981	0.988	0.991	0.993
	k_p	0.969	0.974	0.981	0.984	0.986
	M_T	31.8	39.1	53.0	63.0	73.5
	C/E M_T	1.037	0.991	0.967	0.973	1.039
	C/E k	1.001	1.000	0.999	1.000	1.001

Results: Caliban

From CR worth curves

$\rho = (\rho/\beta_{eff}) \times \beta_{eff} = (\rho/\beta_{eff}) \times 0.00659$

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From CR worth curves

$\rho = (\rho/\beta_{eff}) \times \beta_{eff} = (\rho/\beta_{eff}) \times 0.00659$

$k_{eff} = 1/(1-\rho)$

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Calculated from measured data

Results: Caliban

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From CR worth curves

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Calculated from measured data

Results: Caliban

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	M_T	31.8	39.1	53.0	63.0	73.5
	C/E M_T	1.037	0.991	0.967	0.973	1.039
	C/E k	1.001	1.000	0.999	1.000	1.001

Bias was determined from ICSBEP benchmark configuration at DC.

Assumed to be constant for all configurations.

Results: Godiva

	Configuration	S7	S8	S9	S10	S11	S12
Control rod worth curves	ρ/β ($)	-2.07	-2.00	-1.50	-1.00	-0.75	-0.50
	ρ	-0.014	-0.013	-0.010	-0.007	-0.005	-0.003
	k_{eff}	0.987	0.987	0.990	0.993	0.995	0.997
	k_p	0.980	0.980	0.984	0.987	0.989	0.990
	M_T	50.0	51.2	61.3	76.4	87.1	101.5
NPOD Feynman Analysis	M_T	60.7	62.6	72.5	82.7	89.1	94.7
	k_p	0.984	0.984	0.986	0.988	0.989	0.989
	k_{eff}	0.990	0.991	0.993	0.994	0.995	0.996
	C/E M_T	0.824	0.818	0.846	0.924	0.978	1.072
	C/E k	0.996	0.996	0.997	0.999	1.000	1.001
MCNP KCODE (bias adjusted)	k_{eff}	0.986	0.987	0.990	0.993	0.995	0.996
	k_p	0.979	0.980	0.984	0.986	0.988	0.990
	M_T	48.0	50.3	60.7	73.2	85.5	97.0
	C/E M_T	1.042	1.019	1.010	1.043	1.019	1.046
	C/E k	1.001	1.000	1.000	1.001	1.000	1.000

Results

	Assembly	Godiva	CALIBAN	Godiva	CALIBAN	Godiva	CALIBAN
Control rod worth curves	ρ/β ($)	-2.00		-1.50		-1.00	
	ρ	-0.013		-0.010		-0.007	
	k_{eff}	0.987		0.990		0.993	
	k_p	0.980		0.984		0.987	
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NPOD Feynman Analysis	M_T	62.6	65.7	72.5	75.7	82.7	86.7
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	C/E M_T	0.818	0.780	0.846	0.809	0.924	0.881
	C/E k	0.996	0.996	0.997	0.997	0.999	0.998

Results: Delayed Critical

	Assembly	CALIBAN	Godiva	CALIBAN	Godiva
	Configuration	DC1	DC2	DC2	DC3
	Position	2	-	1	-
	Cf source	Yes	Yes	No	No
Delayed critical definition	ρ/β ($)	0			
	ρ	0			
	k_{eff}	1.000			
	k_p	0.993			
	M_T	151.7			
NPOD Feynman Analysis	M_T	170.9	182.4	177.1	127.7
	k_p	0.994	0.995	0.994	0.992
	k_{eff}	1.001	1.001	1.001	0.999
	ρ	7.43E-04	1.11E-03	9.49E-04	-1.25E-03
	ρ/β ($)	0.11	0.17	0.14	-0.19
	C/E M_T	0.888	0.832	0.857	1.189
	C/E k	0.999	0.999	0.999	1.001
MCNP KCODE (bias adjusted)	k_{eff}	0.999	1.000	1.000	1.001
	k_p	0.992	0.993	0.993	0.994
	M_T	131.7	144.3	152.2	165.5
	C/E M_T	1.152	1.051	0.997	0.917
	C/E k	1.001	1.000	1.000	0.999

When the system is at delayed critical, $k_p = k_{eff}(1-\beta_{eff}) = 1-\beta_{eff}$.

Therefore one can used the measured k_p value to determine $\beta_{eff.}$

Source	Caliban	Godiva	Assumed
Yes	585	548	659
No	565	783	

Results: Positive Period

Caliban

	Configuration	PP1	PP2
Desired configuration	Reactor Period (sec)	500	60
	ρ/β ($)	0.02	0.14
	k_{eff}	1.000	1.001
	k_p	0.994	0.994
	M_T	155.5	177.1
Valduc detectors	Reactor Period (sec)	508	61
	ρ/β ($)	0.02	0.14
	k_{eff}	1.000	1.001
	k_p	0.994	0.994
	M_T	155.4	176.8
NPOD count rate	Reactor Period (sec)	526	68
	ρ/β ($)	0.02	0.13
	k_{eff}	1.000	1.001
	k_p	0.994	0.994
	M_T	155.3	174.6

Godiva-IV

	Configuration	PP1	PP2	PP3
Desired configuration	Reactor Period (sec)	500	180	120
	ρ/β ($)	0.02	0.06	0.08
	k_{eff}	1.000	1.000	1.001
	k_p	0.994	0.994	0.994
	M_T	155.4	161.2	165.3
Startups (pulse mode)	Reactor Period (sec)	489	189	117
	ρ/β ($)	0.02	0.06	0.08
	k_{eff}	1.000	1.000	1.001
	k_p	0.994	0.994	0.994
	M_T	155.5	160.8	165.6
Linears (current mode)	Reactor Period (sec)	490	195	118
	ρ/β ($)	0.02	0.06	0.08
	k_{eff}	1.000	1.000	1.001
	k_p	0.994	0.994	0.994
	M_T	155.4	160.5	165.5
NPOD count rate	Reactor Period (sec)	546	208	133
	ρ/β ($)	0.02	0.05	0.08
	k_{eff}	1.000	1.000	1.000
	k_p	0.994	0.994	0.994
	M_T	155.1	160.0	164.1

Conclusions

- Joint CEA/LANL measurements performed on four critical assembly machines (this work only focused on Caliban and Godiva-IV results).
- Over 50 configurations were measured. Configurations were at various subcritical multiplications as well as at and above delayed critical.
- Results were favorable:
  - The largest Δk_{eff} between the measured data and the control rod worth curves was 0.008.
  - The largest Δk_{eff} between the measured and simulated data was 0.009.

Future Work

- CEA
  - Chapelle to defend thesis in May 2014.
- US
  - Apply recent subcritical uncertainty analysis to all measured data.
  - Document list-mode simulations for all configurations.
  - Analyze Planet and Flat-Top results (“best” nubar for Flat-Top?).
  - Investigate SCRAM and other measurements.

Documents related to this collaboration

- A. Chapelle, P. Casoli, “Neutron Noise Measurements on Caliban Reactor: Kinetic Parameters and Associated Uncertainties Evaluation,” LANL/CEA Workshop, Los Alamos, NM, Nov. 29, 2012.
- J. Hutchinson, et. al., “LANL CALIBAN Subcritical Measurements,” LANL/CEA Workshop, Los Alamos, NM, November 29, 2012.
- A. Chapelle, et. al., “Joint Neutron Noise Measurements on Metallic Reactor Caliban,” Nuclear Data, New York, March 4-8, 2013.
- J. Hutchinson, et. al., “Experimental Results of Joint LANL/CEA Measurements on CALIBAN,” ANS Annual Meeting, Atlanta, GA, June 17-21, 2013.
- A. Chapelle, et. al., “Joint Neutron Noise Measurements on Metallic Reactor Caliban,” ANIMMA, Marseille, France, June 23-27, 2013.
- J. Hutchinson, et. al., “CALIBAN Measurements Near Delayed Critical Using Subcritical Measurement Methods,” ANS Winter Meeting, Washington DC, November 11-15, 2013.
- B. Richard, et. al., “Simulation of Subcritical Neutron Noise Measurements on Caliban,” Draft.
- A. Chapelle, PHD Thesis, Caen University, 2014.

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