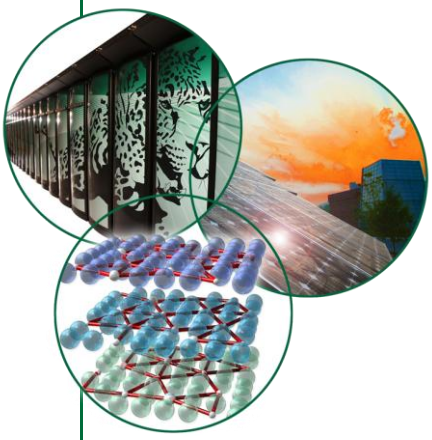
SILENE Benchmark Experiment for Criticality Accident Alarm Systems

Evaluation Progress in FY 2011

Thomas M. Miller
Oak Ridge National Laboratory
Reactor and Nuclear Systems Division



U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Outline

- Brief review of the SILENE CAAS benchmark
- Work performed jointly with the CEA
- Progress on benchmark evaluation
  - Comparison between calculations and measurements for pulse 1
  - Issues encountered and their resolutions
- Future work (FY 2012 and 2013)

Experimental configurations

- Pulse 1
  - SILENE bare (no reflector)
  - Collimator A – unshielded
    - Full set of neutron activation foils
    - Valduc Al_2O_3, ORNL HBG & DXT TLDs
    - Rocky Flats CAAS
  - Collimator B – 20 cm barite concrete
    - Full set of neutron activation foils
    - Valduc Al_2O_3, ORNL HBG & DXT TLDs
    - Rocky Flats & CIDAS CAAS
  - Free-field location
    - Full set of neutron activation foils
    - Valduc Al_2O_3, ORNL HBG & DXT TLDs
  - Scattering Box (2 magnetite & 4 standard concrete shields)
    - Full set of neutron activation foils
    - 3 partial sets of neutron activation foils
    - Valduc Al_2O_3, ORNL HBG & DXT TLDs
    - 2 additional HBG and DXT TLDs
    - 4 additional Valduc Al_2O_3 TLDs
    - Rocky Flats & CIDAS CAAS

- Pulse 2 modifications
  - SILENE with lead reflector (shield)
  - Collimator B barite concrete replaced by standard concrete

- Pulse 3 modifications
  - SILENE with cadmium lined polyethylene reflector (shield)
  - Collimator B concrete replaced by 3” (7.62 cm) of BoroBond

Photographs of bare SILENE and pulse 1 cell configuration

Photographs of scattering box and collimators

Photographs of SILENE with polyethylene and lead shields/reflectors

Summary of individual pulses
Comments on experimental results

	Pulse 1	Pulse 2	Pulse 3
SILENE Shield	Bare	Lead	Polyethylene
Critical Height (cm)	37.333	31.322	34.641
Final Height (cm)	41.871	34.560	38.541
Number of Fissions†	1.88e17	2.14e17	1.92e17
Duration of Pulse (sec)	7	6	6

†The relative uncertainty on the number of fissions is ~4% (1 sigma)

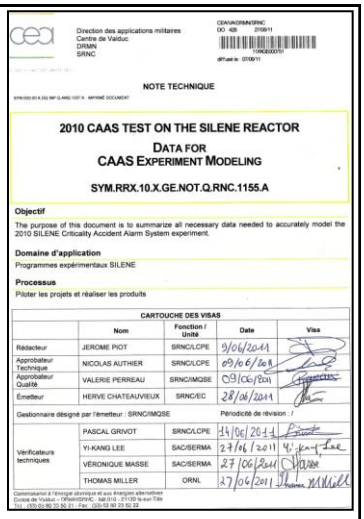
- Neutron foil activities
  - Pulse 1 results are presented in Table III of 2011 ICNC paper
  - Pulse 2 and 3 results will be released in June 2012
- TLD doses
  - Pulse 1 results for Valduc Al_2O_3 TLD are presented in Table IV of ICNC paper
  - Pulse 2 and 3 Valduc Al_2O_3 TLD results will be released in June 2012
  - All ORNL HBG and DXT TLD results for pulse 1 – 3 are presented in Table IV of the 2011 ICNC paper

Status of benchmark in C_EdT process

- CED-0 justification of integral experiment need, approved early 2010
- CED-1 integral experiment conceptual design, approved July 19, 2010
- CED-2 integral experiment final design, approved September 27, 2010
- CED-3a approval to conduct integral experiment September 27, 2010, and experiments conducted October 2010
- CED-3b collect data needed to fully document experiment finalize section 1 of ICSBEP benchmark document, initiated on April 1, 2011
- CED-4 publication of data, future work

Work performed with CEA

- Produced a CEA report to summarize and document the geometric and material data for the three experiments
- Performed a chemical analysis of the foils from the same lot as those used in the experiments
- Investigated additional information concerning the composition of the concrete shields



Direction des applications militaires
Centre de Valduc
DRMN
SRNC

NOTE TECHNIQUE

2010 CAAS TEST ON THE SILENE REACTOR
DATA FOR CAAS EXPERIMENT MODELING

SYM.RRX.10.X.GE.NOT.Q.RNC.1155.A

Objectif
The purpose of this document is to summarize all necessary data needed to accurately model the 2010 SILENE Criticality Accident Alarm System experiment.

Domaine d'application
Programmes expérimentaux SILENE

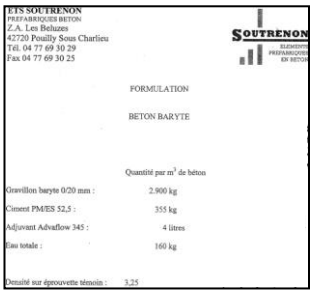
Processus
Piloter les projets et réaliser les produits

CARTOUCHE DES VISAS

	Nom	Fonction / Unité	Date	Visa
Rédacteur	JEROME PIOT	SRNC/LCPE	9/06/2011	
Approbateur Technique	NICOLAS AUTHIER	SRNC/LCPE	09/06/2011	
Approbateur Qualité	VALERIE PERREAU	SRNC/IMQSE	09/06/2011	
Émetteur	HERVE CHATEAUVIEUX	SRNC/EC	28/06/2011	

Gestionnaire désigné par l'émetteur : SRNC/IMQSE — Périodicité de révision : /

Vérificateurs techniques	PASCAL GRIVOT	SRNC/LCPE	14/06/2011	
	YI-KANG LEE	SAC/SERMA	27/06/2011	
	VÉRONIQUE MASSE	SAC/SERMA	27/06/2011	
	THOMAS MILLER	ORNL	27/06/2011	



ETS SOUTRENON
PREFABRIQUES BETON
Z.A. Les Beluzes
42720 Pouilly Sous Charlieu
Tél. 04 77 69 30 29
Fax 04 77 69 30 25

SOUTRENON
ELEMENTS PREFABRIQUES EN BETON

FORMULATION

BETON BARYTE

Quantité par m³ de béton

Gravillon baryte 0/20 mm :	2.900 kg
Ciment PM/ES 52,5 :	355 kg
Adjuvant Advaflow 345 :	4 litres
Eau totale :	160 kg
Densité sur éprouvette témoin :	3,25

Progress of benchmark evaluation (1)

- Issues discussed in previous presentations (indirectly mentioned on the previous slide)
  - Differences between measured and calculated ^{56}Mn activity
  - Differences between measured and calculated activities of foils behind concrete shields

Scale 6.1 computational results for ^{56}Mn activity [^{56}Fe(n,p)^{56}Mn + ^{55}Mn(n,γ)^{56}Mn]

Position	Ratio: C/E	Relative Uncertainty (2 sigma)
Collimator A	1.05	9.5%
Collimator B		
Free Field Location	1.09	8.8%
Scattering Box 1	0.84	8.4%

Collimator B neutron activation foil Scale 6.1 computational results

Position	Reaction	Ratio: C/E	Relative Uncertainty (2 sigma)
Fast	^{115}In(n,n'γ)^{115m}In	0.17	8.7%
	^{54}Fe(n,p)^{54}Mn	0.24	8.9%
	^{24}Mg(n,p)^{24}Na	0.46	11.0%
	^{58}Ni(n,p)^{58}Co	0.23	8.7%
Thermal	^{197}Au(n,γ)^{198}Au	0.07	8.6%
	^{115}In(n,γ)^{116}In	0.08	8.8%
	^{59}Co(n,γ)^{59}Co	0.06	8.4%
^{56}Mn		0.07	8.5%
Al_2O_3		0.60	9.2%
HBG		0.55	10.7%

Progress of benchmark evaluation (2)

- Comparison of reaction cross sections (ENDF/B-VII.0 vs. IRDF-2002)
  - In most cases ENDF and IRDF produce similar results
  - Exceptions: $^{115}In(n,n'\gamma)^{115m}In$ & $^{197}Au(n,\gamma)^{198}Au$

$^{115}In(n,n'\gamma)^{115m}In$ Activity SCALE 6.1 Computational Results					
		ENDF		IRDF	
Position	**Reaction**	**Ratio: C/E**	**Relative Uncertainty (2 sigma)**	**Ratio: C/E**	**Relative Uncertainty (2 sigma)**
Collimator A	$^{115}In(n,n'\gamma)^{115m}In$	0.07	10.7%	0.95	9.5%
Collimator B					
Free Field Location	$^{115}In(n,n'\gamma)^{115m}In$	0.07	10.2%	0.96	9.2%
Scattering Box 1	$^{115}In(n,n'\gamma)^{115m}In$	0.03	14.4%	0.38	10.1%

Progress of benchmark evaluation (2)

- Comparison of reaction cross sections (ENDF/B-VII.0 vs. IRDF-2002)
  - In most cases ENDF and IRDF produce similar results
  - Exceptions: $^{115}In(n,n'\gamma)^{115m}In$ & $^{197}Au(n,\gamma)^{198}Au$

$^{115}In(n,n'\gamma)^{115m}In$ Activity SCALE 6.1 Computational Results					
		ENDF		IRDF	
Position	**Reaction**	**Ratio: C/E**	**Relative Uncertainty (2 sigma)**	**Ratio: C/E**	**Relative Uncertainty (2 sigma)**
Collimator A	$^{115}In(n,n'\gamma)^{115m}In$	0.07	10.7%	0.95	9.5%
Collimator B					
Free Field Location	$^{115}In(n,n'\gamma)^{115m}In$	0.07	10.2%	0.96	9.2%
Scattering Box 1	$^{115}In(n,n'\gamma)^{115m}In$	0.03	14.4%	0.38	10.1%

We will discuss this shortly

Progress of benchmark evaluation (3)

– However, the Au exception may be the result of a bad measurement and uncertainty about the magnetite concrete composition

$^{197}Au(n,\gamma)^{198}Au$ Activity SCALE 6.1 Computational Results					
		ENDF		IRDF	
Position	**Reaction**	**Ratio: C/E**	**Relative Uncertainty (2 sigma)**	**Ratio: C/E**	**Relative Uncertainty (2 sigma)**
Collimator A	$^{197}Au(n,\gamma)^{198}Au$	0.47	8.9%	0.97	9.5%
Collimator B					
Free Field Location	$^{197}Au(n,\gamma)^{198}Au$	1.09	9.0%	1.91	10.2%
Scattering Box 1	$^{197}Au(n,\gamma)^{198}Au$	0.79	8.7%	1.12	9.3%
Scattering Box 2	$^{197}Au(n,\gamma)^{198}Au$	0.85	8.8%	1.18	9.4%
Scattering Box 3	$^{197}Au(n,\gamma)^{198}Au$	0.97	8.7%	1.54	9.2%
Scattering Box 4	$^{197}Au(n,\gamma)^{198}Au$	0.97	8.7%	1.41	9.1%

Progress of benchmark evaluation (3)

– However, the Au exception may be the result of a bad measurement and uncertainty about the magnetite concrete composition

$^{197}Au(n,\gamma)^{198}Au$ Activity SCALE 6.1 Computational Results					
		ENDF		IRDF	
Position	**Reaction**	**Ratio: C/E**	**Relative Uncertainty (2 sigma)**	**Ratio: C/E**	**Relative Uncertainty (2 sigma)**
Collimator A	$^{197}Au(n,\gamma)^{198}Au$	0.47	8.9%	0.97	9.5%
Collimator B					
Free Field Location	$^{197}Au(n,\gamma)^{198}Au$	1.09	9.0%	1.91	10.2%
Scattering Box 1	$^{197}Au(n,\gamma)^{198}Au$	0.79	8.7%		
Scattering Box 2	$^{197}Au(n,\gamma)^{198}Au$	0.85	8.8%		
Scattering Box 3	$^{197}Au(n,\gamma)^{198}Au$	0.97	8.7%		
Scattering Box 4	$^{197}Au(n,\gamma)^{198}Au$	0.97	8.7%		

Measurement Data (Bq/g)				
	Reaction	**Collimator A**	**Free Field**	**Ratio CA/FF**
Thermal	$^{197}Au(n,\gamma)^{198}Au$	181200	69500	2.61
	$^{115}In(n,\gamma)^{116}In$	9.11E+06	8.78E+06	1.04
	$^{59}Co(n,\gamma)^{60}Co$	66.1	66.2	1.00
56Mn		2310	2403	0.96
Fast	$^{58}Ni(n,p)^{58}Co$	14.36	12.99	1.11
	$^{115}In(n,n'\gamma)^{115m}In$	8030	6860	1.17
	$^{54}Fe(n,p)^{54}Mn$	0.2062	0.1961	1.05
	$^{24}Mg(n,p)^{24}Na$	61.1	59.1	1.03
Al2O3		6.61	3.72	1.78
HBG		6.03	5.02	1.20

Progress of benchmark evaluation (3)

- However, the Au exception may be the result of a bad measurement and uncertainty about the magnetite concrete composition

$^{197}Au(n,\gamma)^{198}Au$ Activity SCALE 6.1 Computational Results					
		ENDF		IRDF	
Position	Reaction	Ratio: C/E	Relative Uncertainty (2 sigma)	Ratio: C/E	Relative Uncertainty (2 sigma)
Collimator A	$^{197}Au(n,\gamma)^{198}Au$	0.47	8.9%	0.97	9.5%
Collimator B					
Free Field Location	$^{197}Au(n,\gamma)^{198}Au$	1.09	9.0%	1.91	10.2%
Scattering Box 1	$^{197}Au(n,\gamma)^{198}Au$	0.79	8.7%		
Scattering Box 2	$^{197}Au(n,\gamma)^{198}Au$	0.85	8.8%		
Scattering Box 3	$^{197}Au(n,\gamma)^{198}Au$	0.97	8.7%		
Scattering Box 4	$^{197}Au(n,\gamma)^{198}Au$	0.97	8.7%		

Next let's discuss the shielded scattering box locations

Measurement Data (Bq/g)				
	Reaction	Collimator A	Free Field	Ratio CA/FF
Thermal	$^{197}Au(n,\gamma)^{198}Au$	181200	69500	2.61
	$^{115}In(n,\gamma)^{116}In$	9.11E+06	8.78E+06	1.04
	$^{59}Co(n,\gamma)^{60}Co$	66.1	66.2	1.00
56Mn		2310	2403	0.96
Fast	$^{58}Ni(n,p)^{58}Co$	14.36	12.99	1.11
	$^{115}In(n,n'\gamma)^{115m}In$	8030	6860	1.17
	$^{54}Fe(n,p)^{54}Mn$	0.2062	0.1961	1.05
	$^{24}Mg(n,p)^{24}Na$	61.1	59.1	1.03
Al2O3		6.61	3.72	1.78
HBG		6.03	5.02	1.20

Then discuss the TLDs

Progress of benchmark evaluation (4)

- Comparison of calculations and measurements in the scattering box
  - Attempts have been made to adjust the hydrogen content of the concrete shields
  - But this was done without adjusting the density

Fast neutron activation foil SCALE 6.1 computational results			
Position	Reaction	Minimum H Content Ratio: C/E	Maximum H Content Ratio: C/E
Scattering Box 1	$^{115}In(n,n'\gamma)^{115m}In$	1.08	0.38
	$^{54}Fe(n,p)^{54}Mn$	1.19	0.47
	$^{24}Mg(n,p)^{24}Na$	---	---
	$^{58}Ni(n,p)^{58}Co$	1.22	0.48
Scattering Box 2	$^{58}Ni(n,p)^{58}Co$	1.59	0.70
Scattering Box 3	$^{58}Ni(n,p)^{58}Co$	1.01	0.86
Scattering Box 4	$^{58}Ni(n,p)^{58}Co$	1.04	0.94

Thermal neutron activation foil SCALE 6.1 computational results			
Position	Reaction	Minimum H Content Ratio: C/E	Maximum H Content Ratio: C/E
Scattering Box 1	$^{197}Au(n,\gamma)^{198}Au$	0.71	0.79
	$^{115}In(n,\gamma)^{116}In$	0.89	1.01
	$^{59}Co(n,\gamma)^{59}Co$	0.71	0.89
Scattering Box 2	$^{197}Au(n,\gamma)^{198}Au$	0.72	0.85
	$^{59}Co(n,\gamma)^{59}Co$	0.69	0.93
Scattering Box 3	$^{197}Au(n,\gamma)^{198}Au$	0.79	0.97
	$^{59}Co(n,\gamma)^{59}Co$	0.75	0.99
Scattering Box 4	$^{197}Au(n,\gamma)^{198}Au$	0.81	0.97
	$^{59}Co(n,\gamma)^{59}Co$	0.73	0.96

Progress of benchmark evaluation (4)

- Comparison of calculations and measurements in the scattering box
  - Attempts have been made to adjust the hydrogen content of the concrete shields
  - But this was done without adjusting the density

Fast neutron activation foil SCALE 6.1 computational results

Position	Reaction	Minimum H Content Ratio: C/E	Maximum H Content Ratio: C/E
Scattering Box 1	$^{115}In(n,n'\gamma)^{115m}In$	1.08	0.38
	$^{54}Fe(n,p)^{54}Mn$	1.19	0.47
	$^{24}Mg(n,p)^{24}Na$	---	---
	$^{58}Ni(n,p)^{58}Co$	1.22	0.48
Scattering Box 2	$^{58}Ni(n,p)^{58}Co$	1.59	0.70
Scattering Box 3	$^{58}Ni(n,p)^{58}Co$	1.01	0.86
Scattering Box 4	$^{58}Ni(n,p)^{58}Co$	1.04	0.94

Thermal neutron activation foil SCALE 6.1 computational results

Position	Reaction	Minimum H Content Ratio: C/E	Maximum H Content Ratio: C/E
Scattering Box 1	$^{197}Au(n,\gamma)^{198}Au$	0.71	0.79
	$^{115}In(n,\gamma)^{116}In$	0.89	1.01
	$^{59}Co(n,\gamma)^{59}Co$	0.71	0.89
Scattering Box 2	$^{197}Au(n,\gamma)^{198}Au$	0.72	0.85
	$^{59}Co(n,\gamma)^{59}Co$	0.69	0.93
Scattering Box 3	$^{197}Au(n,\gamma)^{198}Au$	0.79	0.97
	$^{59}Co(n,\gamma)^{59}Co$	0.75	0.99
Scattering Box 4	$^{197}Au(n,\gamma)^{198}Au$	0.81	0.97
	$^{59}Co(n,\gamma)^{59}Co$	0.73	0.96

It seems possible that adjustments of the hydrogen (water) content and density within the uncertainties could improve the overall agreement in the scattering box

Progress of benchmark evaluation (5)

- Comparison of calculations and measurements for TLDs
  - Similar to the Au measurement in Collimator A, the Valduc free field TLD seems incorrect
  - All of these kerma values only include response due to fission neutrons and photons (prompt and delayed), i.e., no activation products

TLD kerma SCALE 6.1 computational results

Position	TLD	Ratio: C/E	Relative Uncertainty (2 sigma)
Collimator A	Al_2O_3	0.91	9.7%
	HBG	1.08	13.3%
Collimator B			
Free Field Location	Al_2O_3	1.47	9.9%
	HBG	1.06	11.5%
Scattering Box 1	Al_2O_3	0.77	9.2%
	HBG		
Scattering Box 2	Al_2O_3	0.87	9.0%
	HBG		
Scattering Box 3	Al_2O_3	0.90	8.7%
Scattering Box 4	Al_2O_3	0.88	10.6%

Progress of benchmark evaluation (5)

- Comparison of calculations and measurements for TLDs
  - Similar to the Au measurement in Collimator A, the Valduc free field TLD seems incorrect
  - All of these kerma values only include response due to fission neutrons and photons (prompt and delayed), i.e., no activation products

Measurement Data (kerma in air, Gy)			
Location	**Al2O3**	**HBG**	**Ratio Al2O3/HBG**
Collimator A	6.610	6.030	1.10
Collimator B	0.820	0.874	0.94
Free field	3.720	5.020	0.74
Scattering box 1	0.580	0.576	1.01
Scattering box 2	0.440	0.398	1.11
Scattering box 3	1.760	---	---
Scattering box 4	1.870	---	---

TLD kerma SCALE 6.1 computational results

Position	TLD	Ratio: C/E	Relative Uncertainty (2 sigma)
Collimator A	Al_2O_3	0.91	9.7%
	HBG	1.08	13.3%
Collimator B			
Free Field Location	Al_2O_3	1.47	9.9%
	HBG	1.06	11.5%
Scattering Box 1	Al_2O_3	0.77	9.2%
	HBG		
Scattering Box 2	Al_2O_3	0.87	9.0%
	HBG		
Scattering Box 3	Al_2O_3	0.90	8.7%
Scattering Box 4	Al_2O_3	0.88	10.6%

Progress of benchmark evaluation (6)

- Conclusions
  - Inclusion of ^{55}Mn impurities in the Fe foils is needed to accurately calculate the ^{56}Mn activity
  - Calculating the detector responses in Collimator B for pulse 1 is not possible without a new analysis of the barite concrete composition
  - Improving the calculated detector responses in the scattering box does seem possible
  - With the exception of ^{115}In(n,n'γ)^{115m}In, using ENDF/B-VII.0 reaction cross sections produces results comparable to IRDF-2002
  - The pulse 1 Au activity in Collimator A does not appear correct, particularly when compared to calculations and the Au activity measured at other locations after pulse 1
  - Similarly, the Valduc TLD kerma at the free field location does not appear consistent with calculations and other measurements

Future work (FY 2012 and 2013)

- Finalize refinement of scattering box concrete composition
- Work with CEA Valduc to finalize the neutron activities and Valduc TLD kerma measurements for pulses 2 and 3 (expected June 2012)
- Compare pulse 2 and 3 simulations to newly released data
- Update MCNP models based on recent adjustments made during pulse 1 evaluation
- Continue collaboration with LLNL to develop a COG benchmark model and CEA Saclay to develop a TRIPOLI-4 benchmark model
- Finalize draft benchmark evaluation

Thanks again to all my collaborators

- Oak Ridge National Laboratory
  - Design, measurements, documentation, and evaluation
  - T. M. Miller, M. E. Dunn, J. C. Wagner, and K. L. McMahan
- CEA Valduc
  - Design, irradiation, measurements, and documentation
  - N. Authier, X. Jacquet, G. Rousseau, H. Wolff, J. Piot, L. Savanier, and N. Baclet
- CEA Saclay
  - Shielding materials and evaluation
  - Y. K. Lee, V. Masse, J. C. Trama, E. Gagnier, S. Naury, and R. Lenain
- Lawrence Livermore National Laboratory
  - Rocky Flats CAAS
  - S. Kim and G. M. Dulik
- Babcock International Group
  - CIDAS CAAS
  - R. Hunter
- Y-12 National Security Complex
  - BoroBond shielding materials
  - K. H. Reynolds