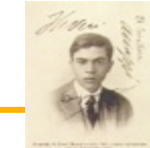
The MAJORANA DEMONSTRATOR



Cosmogenic Induced Backgrounds for the Enriched Germanium Detectors

Brandon White

On Behalf of the

MAJORANA Project

Los Alamos

The MAJORANA Collaboration

Black Hills State University, Spearfish, SD
Kara Keeter

Duke University, Durham, North Carolina, and TUNL
Matthew Busch

Joint Institute for Nuclear Research, Dubna, Russia
Viktor Brudanin, M. Shirchenko, Sergey Vasilyev, E. Yakushev, I. Zhitnikov

Lawrence Berkeley National Laboratory, Berkeley, California and the University of California - Berkeley
Nicolas Abgrall, Yuen-Dat Chan, Lukas Hehn, Jordan Myslik, Alan Poon, Kai Vetter

Los Alamos National Laboratory, Los Alamos, New Mexico
Pinghan Chu, Steven Elliott, Ralph Massarczyk, Keith Rielage, Larry Rodriguez, Harry Salazar, Brandon White, Brian Zhu

National Research Center '*Kurchatov Institute' Institute of Theoretical and Experimental Physics, Moscow, Russia*
Alexander Barabash, Sergey Konovalov, Vladimir Yumatov

North Carolina State University, and TUNL
Matthew P. Green

Oak Ridge National Laboratory
Fred Bertrand, Charlie Havener, Monty Middlebrook, David Radford, Robert Varner, Chang-Hong Yu

Osaka University, Osaka, Japan
Hiroyasu Ejiri

Pacific Northwest National Laboratory, Richland, Washington
Isaac Arnquist, Eric Hoppe, Richard T. Kouzes

Princeton University, Princeton, New Jersey
Graham K. Giovanetti

Queen's University, Kingston, Canada
Ryan Martin

South Dakota School of Mines and Technology, Rapid City, South Dakota
Colter Dunagan, Cabot-Ann Christofferson, Anne-Marie Suriano, Jared Thompson

Tennessee Tech University, Cookeville, Tennessee
Mary Kidd

Technische Universität München, and Max Planck Institute, Munich, Germany
Tobias Bode, Susanne Mertens

University of North Carolina, Chapel Hill, North Carolina, and TUNL
Thomas Caldwell, Thomas Gilliss, Chris Haufe, Reyco Henning, Mark Howe, Samuel J. Meijer, Christopher O' Shaughnessy, Gulden Othman, Jamin Rager, Anna Reine, Benjamin Shanks, Kris Vorren, John F. Wilkerson

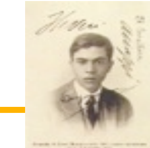
University of South Carolina, Columbia, South Carolina
Frank Avignone, Vince Guiseppe, David Tedeschi, Clint Wiseman

University of South Dakota, Vermillion, South Dakota
CJ Barton, Wenqin Xu

University of Tennessee, Knoxville, Tennessee
Yuri Efremenko, Andrew Lopez

University of Washington, Seattle, Washington
Sebastian Alvis, Tom Burritt, Micah Buuck, Clara Cuesta, Jason Detwiler, Julieta Gruszko, Ian Guinn, David Peterson, Walter Pettus, R. G. Hamish Robertson, Nick Rouf, Tim Van Wechel

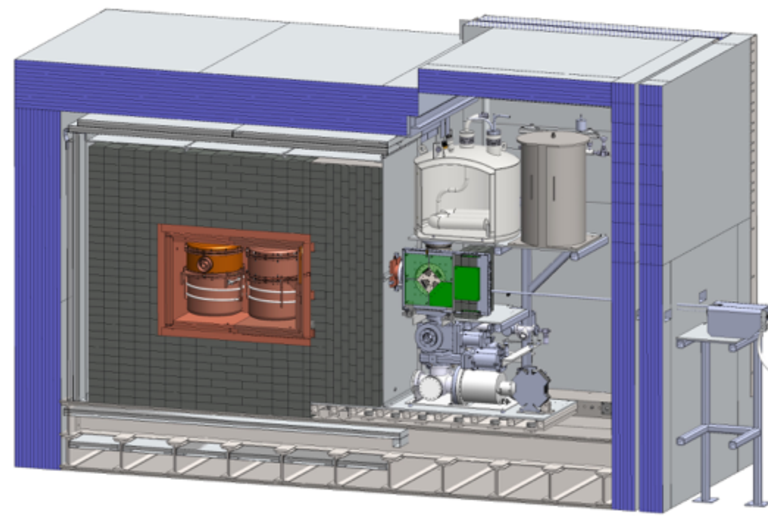
The MAJORANA DEMONSTRATOR



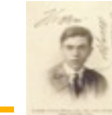
Funded by DOE Office of Nuclear Physics, NSF Particle Astrophysics, NSF Nuclear Physics
with additional contributions from international collaborators.

Goals: - Demonstrate backgrounds low enough to justify building a tonne scale experiment.
- Establish feasibility to construct & field modular arrays of Ge detectors.
- Searches for additional physics beyond the standard model.

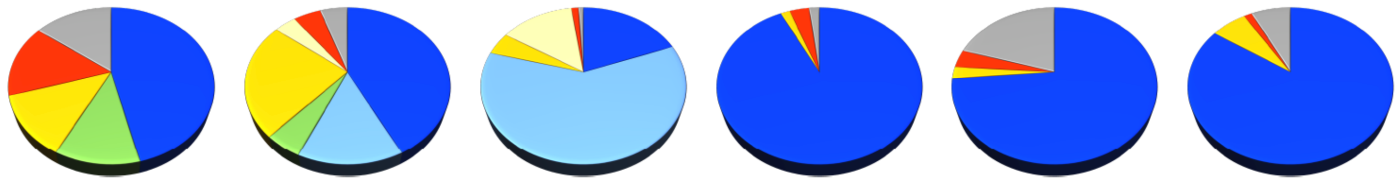
- Located underground at 4850' Sanford Underground Research Facility
- Background Goal in the $0\nu\beta\beta$ peak region of interest (4 keV at 2039 keV)
  3 counts/ROI/t/y (after analysis cuts) Assay U.L. currently ≤ 3.5
  scales to 1 count/ROI/t/y for a tonne experiment
- 44.1-kg of Ge detectors
  - 29.7 kg of 87% enriched ^{76}Ge crystals
  - 14.4 kg of ^{nat}Ge
  - Detector Technology: P-type, point-contact.
- 2 independent cryostats
  - ultra-clean, electroformed Cu
  - 22 kg of detectors per cryostat
  - naturally scalable
- Compact Shield
  - low-background passive Cu and Pb shield with active muon veto



Data Sets



DS-0	DS-1	DS-2	DS-3	DS-4	DS-5



Commissioning, No inner shield	*Inner EFCu shield installed*	*Inner shield & multi-sampling*	*No multi-sampling*	*First Module 2 data*	*First combined M1+M2 dataset*

	DS-0 **Module 1** June 26 – Oct. 7, 2015	**DS-1** **Module 1** Dec. 31, 2015 – May 24, 2016	**DS-2** **Module 1** May 24 – July 14, 2016	**DS-3** **Module 1** Aug. 25 – Sep. 27, 2016	**DS-4** **Module 2** Aug. 25 – Sep. 27, 2016	**DS-5** **Module 1 & 2** Oct. 13, 2016 – ***ongoing*** *
Total (days)	103.15	144.50	50.97	32.37	32.36	97.7
Total acquired	87.93	136.98	50.47	31.73	25.80	90.41
Physics *	47.70	61.34 + 20.41*	9.82 + 30.56*	29.97	23.84	82.52
High radon	11.76	7.32	-	-	-	-
Calibration	15.44	7.32	0.65	1.18	1.17	1.39
Down time	15.21	7.51	0.50	0.64	6.56	7.29
Disruptive/ Commissioning *	13.10	34.43+ 5.92*	2.41 + 7.03*	0.57	0.78	6.51

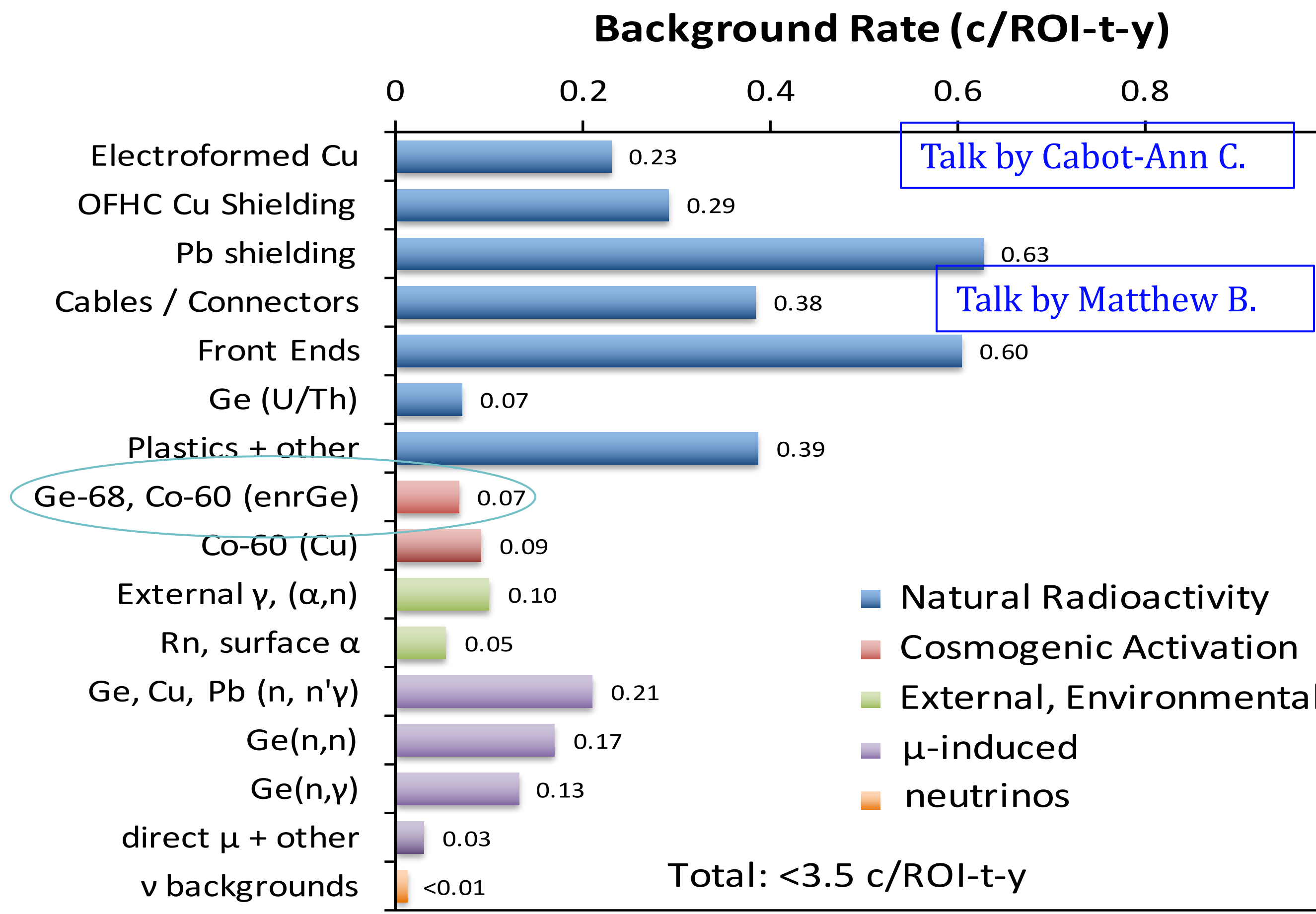
*Blind data

* Values up to Jan. 19, 2017

DEMONSTRATOR Background Model

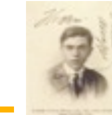
Backgrounds produced from energetic cosmic neutrons interacting with our detectors.

The contribution to our overall background has been kept low by careful planning during detector and material fabrication.



Results from radioassay paper: NIMA 828 (2016) 22

LOW ENERGY PHYSICS



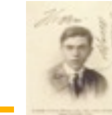
- The extremely low background, energy thresholds, and energy resolution of the MAJORANA DEMONSTRATOR allows for low energy physics searches.

- Bosonic Dark Matter
- Light WIMP searches
- Solar Axions
- Electron decay
- Pauli-Exclusion Principle Violation

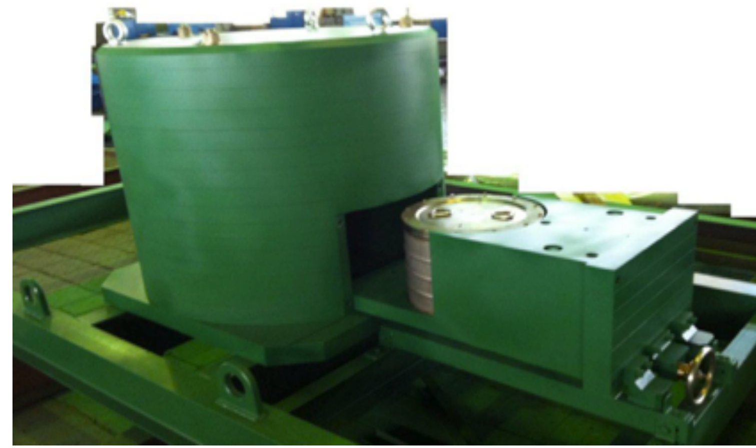
Phys. Rev. Lett. 118, 161801 (2017)

The majority of these searches deal below ~20keV (<100keV for Bosonic Dark Matter).

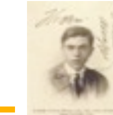
Logistics and Shielding for Enriched Ge



- Enriched at ECP, Russia
- Shipped to USA in shielded container
- Stored at commercial cave in Oak Ridge, TN ~100 m.w.e
- Limit time on the surface during detector fabrication



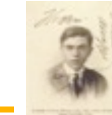
ORTEC
AMETEK

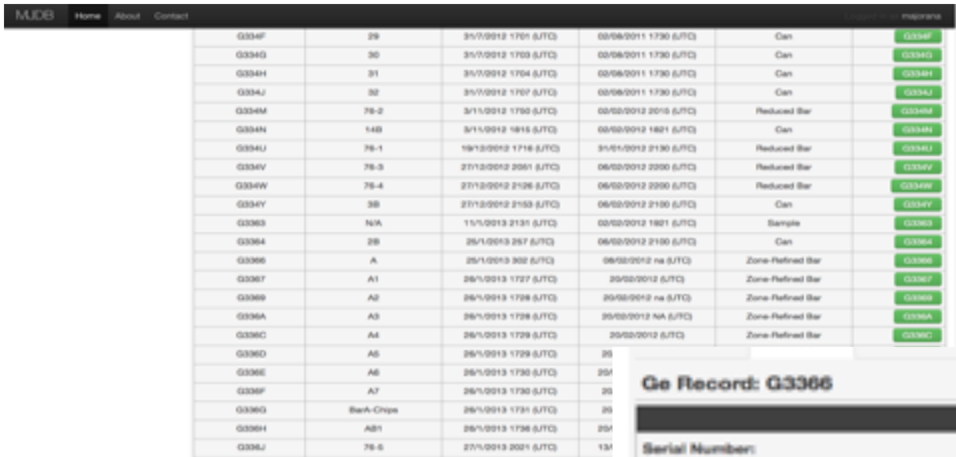


Surface Exposure During Fabrication

- Reducing enriched $Ge0_2$
- Zone Refinement of enriched Ge bars
- Crystal pulling
- Detector cutting and final fabrication

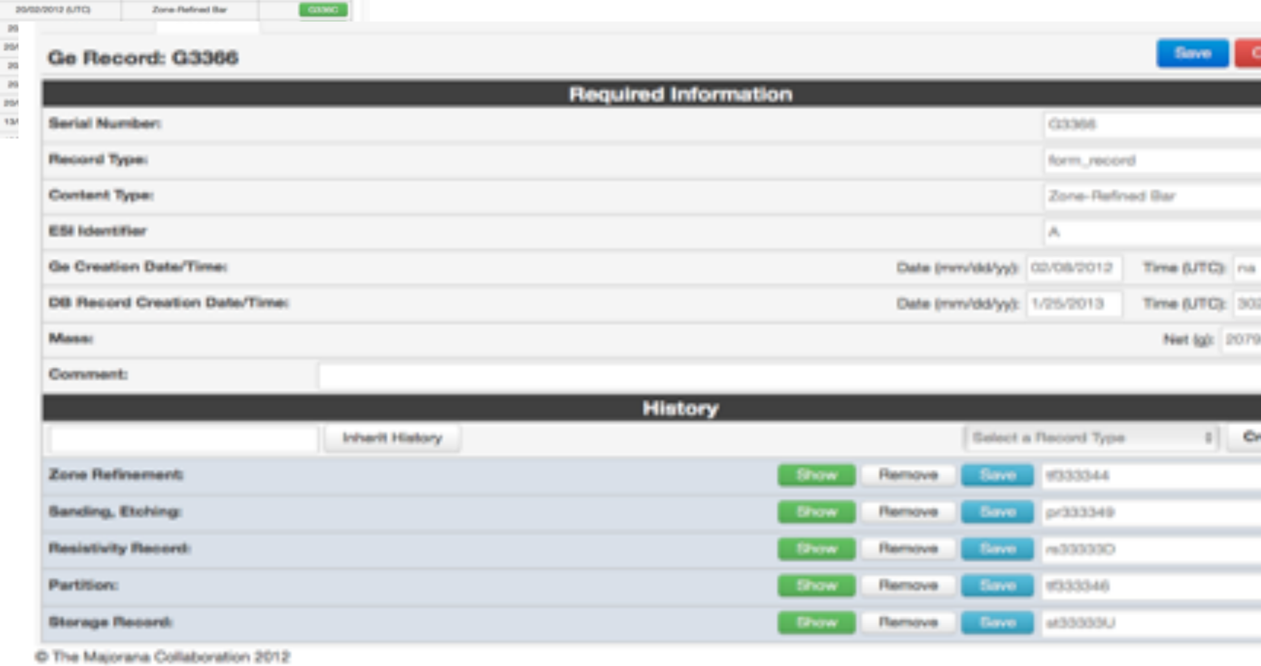
Tracking Database



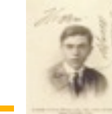


Material history, from enrichment to detector production, is stored in a database.

The detailed information is used to calculate the actual cosmogenic isotope abundance.



Isotope Production



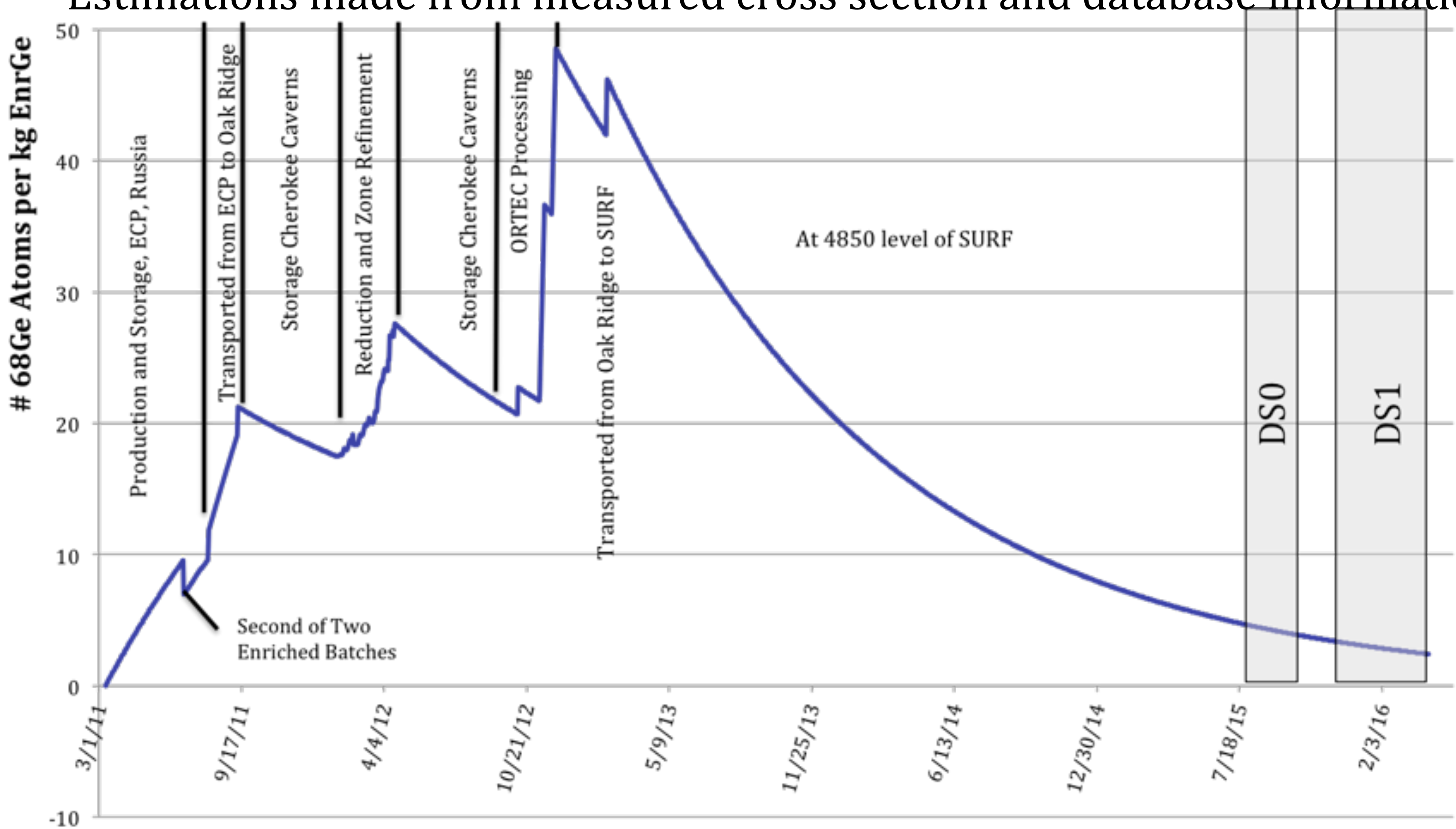
Isotope	Production at Sea Level (atoms/kg/d)
^{54}Mn	2.1 ± 1.0*
^{60}Co	2.6 ± 1.2 *
^{57}Co	0.8 ± 0.4 *
^{68}Ge	2.8 ± 0.5 *
^{65}Zn	9.9 ± 2.8 *
^{55}Fe	4.6 ± 0.7 **
^{3}H	82 ± 21 **

Measurements from Natural Detectors

*Phys.Rev.C82:054610,2010
** Astropart. Phys., 91 (2017), pp. 51-64

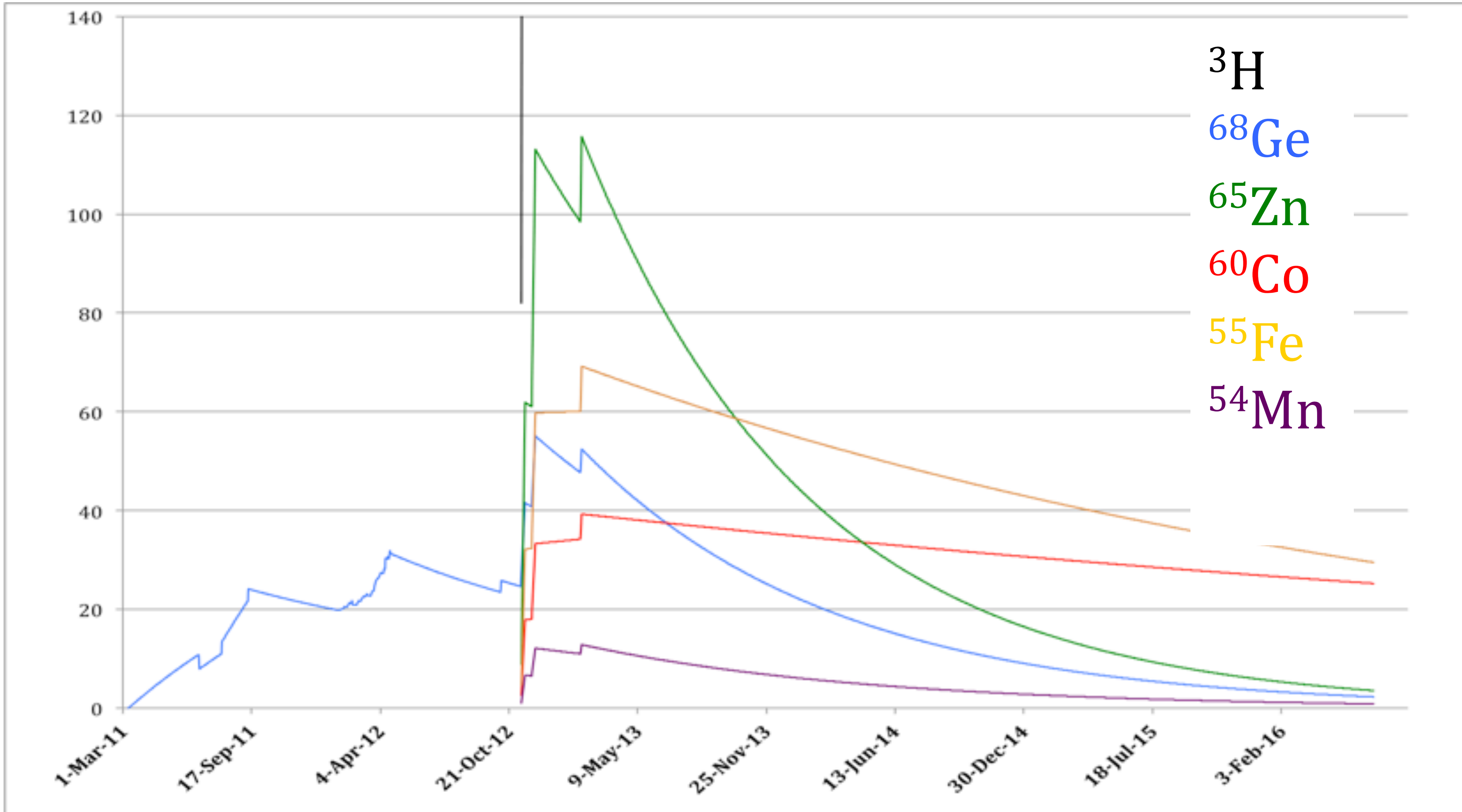
Predicted ^{68}Ge in Detector P42537A

Estimations made from measured cross section and database information.

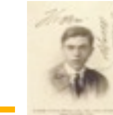


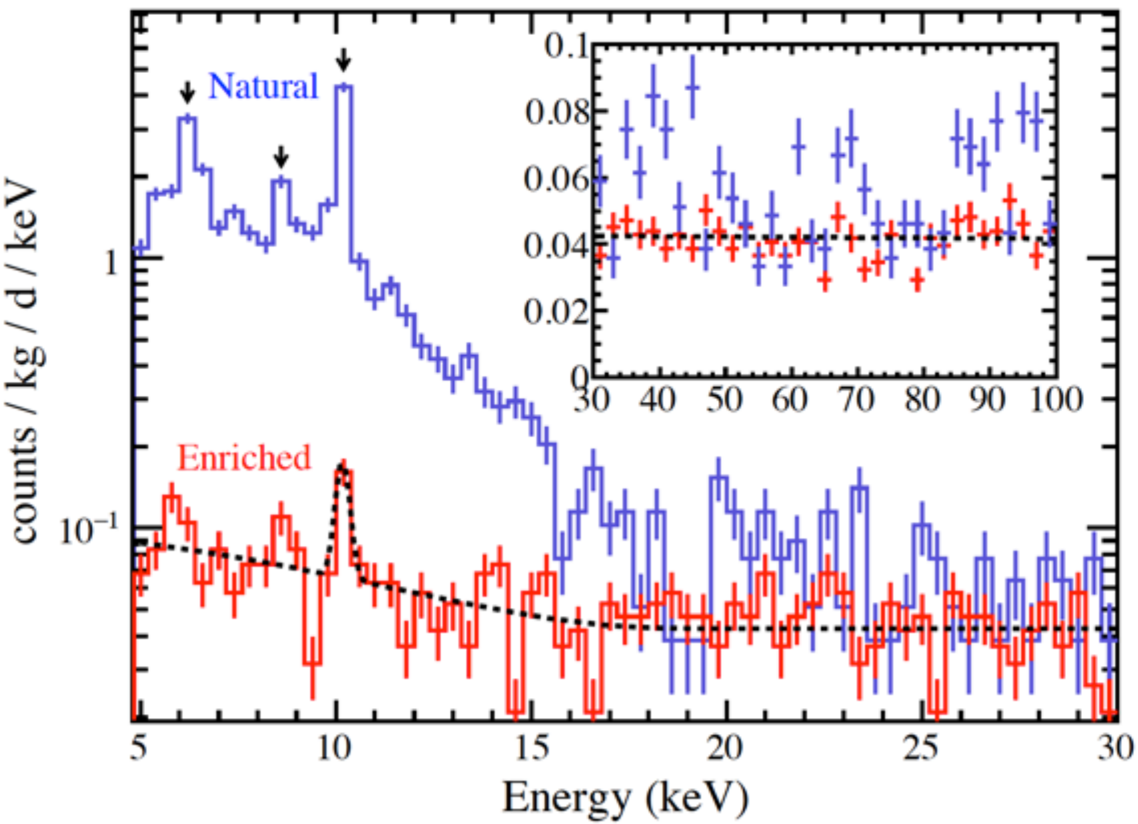
Isotope Production in Detector P42537A

Estimations made from measured cross section and database information.



Data Set 0 – Comparison



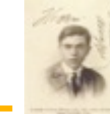


Phys. Rev. Lett. 118, 161801 (2017)

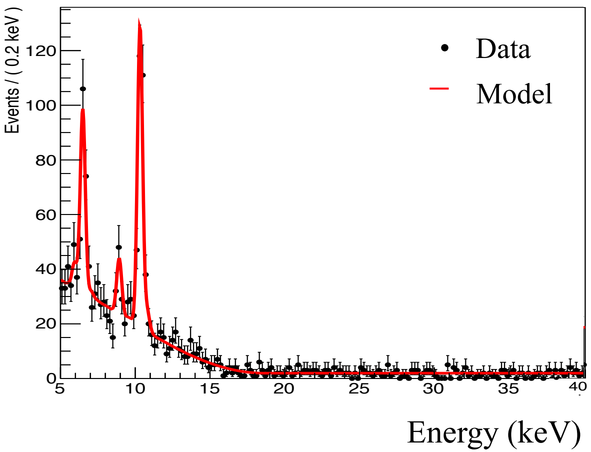
The reduction in the low energy events can be seen between our enriched and natural detectors.

The natural detectors spent significant surface time in Los Alamos and production was not closely tracked.

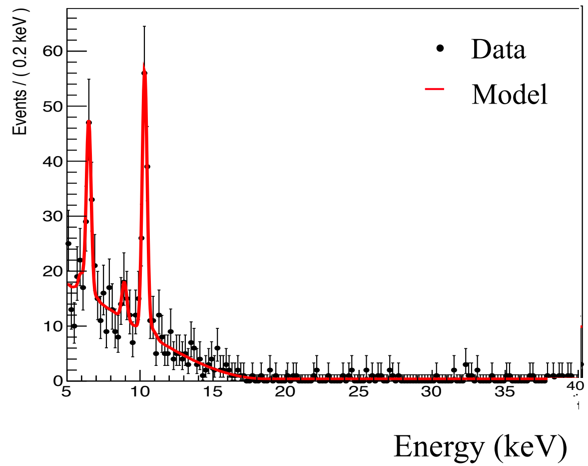
Data Sets – Natural Detectors



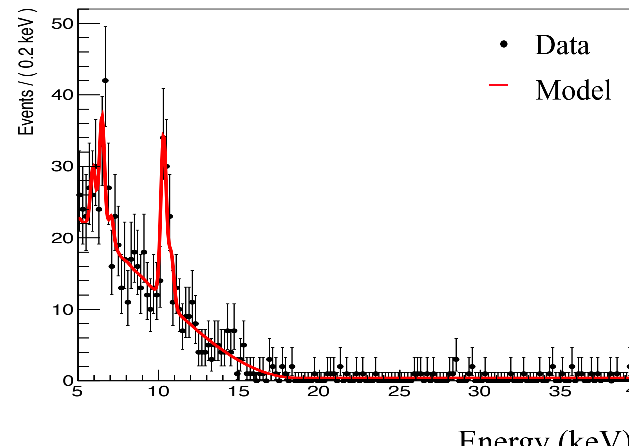
Data Set 0



Data Set 1



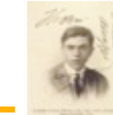
Data Set 3



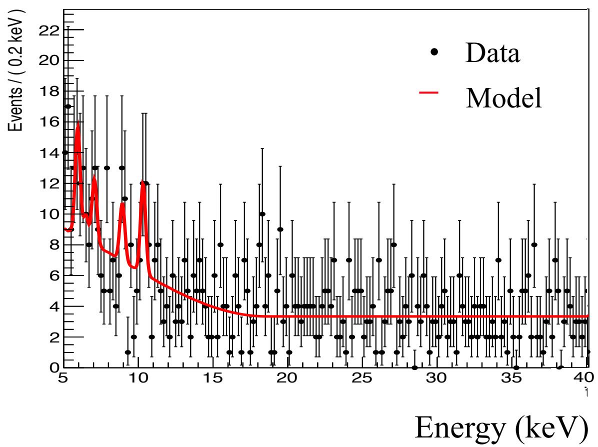
The fitting model is comprised of a calculated tritium beta-decay spectrum, flat background, and multiple X-ray peaks.

Isotope	Daughter K-Shell Binding Energy (keV)
^{68}Ge	10.37
^{54}Mn	5.99
^{55}Fe	6.54
^{57}Co	7.11
^{65}Zn	8.98
^{68}Ga	9.66
^{72}Se	11.87

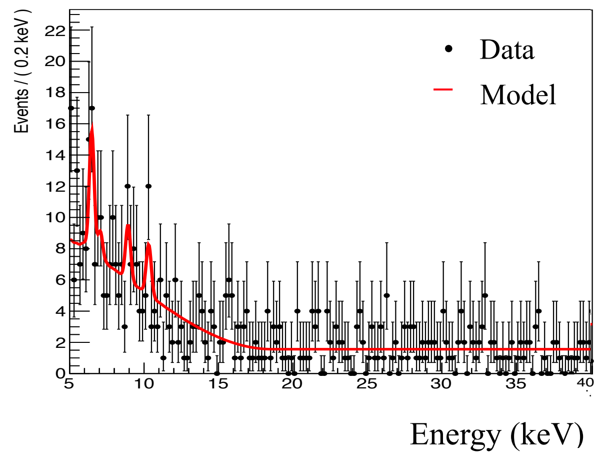
Data Sets – Enriched Detectors



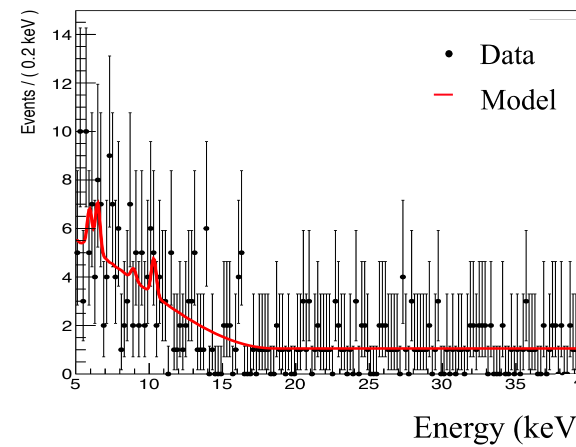
Data Set 0



Data Set 1



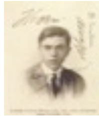
Data Set 3



The fitting model is comprised of a calculated tritium beta-decay spectrum, flat background, and multiple X-ray peaks.

Isotope	Daughter K-Shell Binding Energy (keV)
^{68}Ge	10.37
^{54}Mn	5.99
^{55}Fe	6.54
^{57}Co	7.11
^{65}Zn	8.98
^{68}Ga	9.66
^{72}Se	11.87

Fit Results Extrapolated Back to June 26, 2015



Abundance for given isotopes.

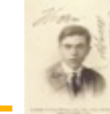
Preliminary

Isotope	Data Set	Extrapolated from Data (atoms per kg)	Estimated abundance (atoms per kg)
^{68}Ge	DS0	13 ± 6	9.5 +3.8 -2.4
	DS1	9.7 ± 8.0	
	DS3	9.3 ± 11	
^{55}Fe	DS0	6.6 ± 17	6.6 +3.5 -2.2
	DS1	86 ± 29	
	DS3	21 ± 24	
^{54}Mn	DS0	20 ± 21	9.9 +7.8 -5.4
	DS1	0 ± 13	
	DS3	39 ± 48	
^{65}Zn	DS0	5.0 ± 6.9	29 +15 -10
	DS1	21 ± 14	
	DS3	7.6 ± 23	
^{3}H	DS0	3300 ± 600	3600 +1800 -1100
	DS1	5700 ± 600	
	DS3	3200 ± 500	

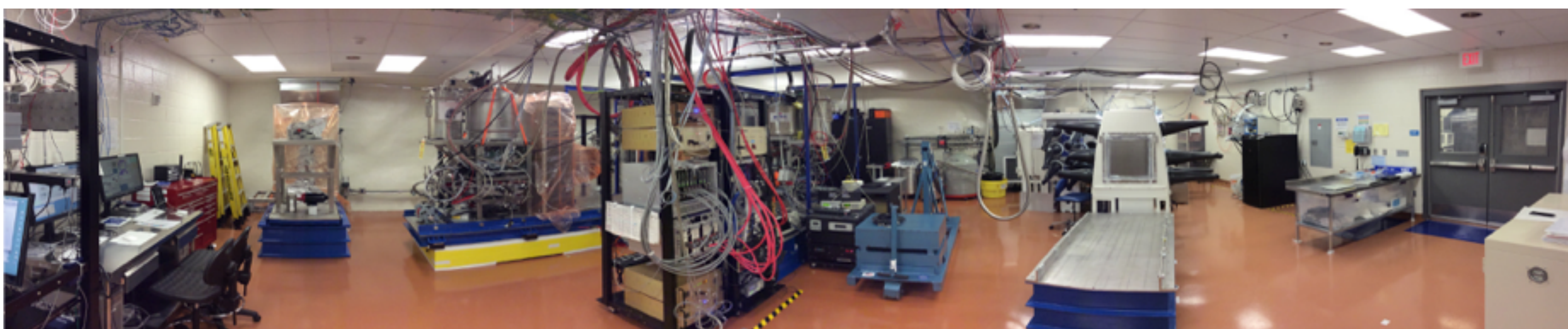
Activation rates from abundance measurements

Isotope	Activation from Data (atoms/kg d)	Activation Used for Estimation (atoms/kg d)
^{68}Ge	3.3 ± 1.6	2.8 ± 0.5
^{55}Fe	2.1 ± 0.7	9.9 ± 2.8
^{54}Mn	4.4 ± 4.1	2.1 ± 1.0
^{65}Zn	4.3 ± 3.6	9.9 ± 2.8
^{3}H	140 ± 10	82 ± 21

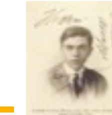
Summary



- Without careful planning cosmogenic induced backgrounds can become a major factor in an ultra-low background experiment.
- Steps have been taken throughout the enriched Ge detector production to ensure limited exposure to cosmogenic-neutrons.
- Our campaign will limit the long lived isotope events in our detector arrays.

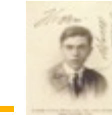


Acknowledgements

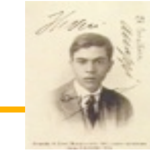


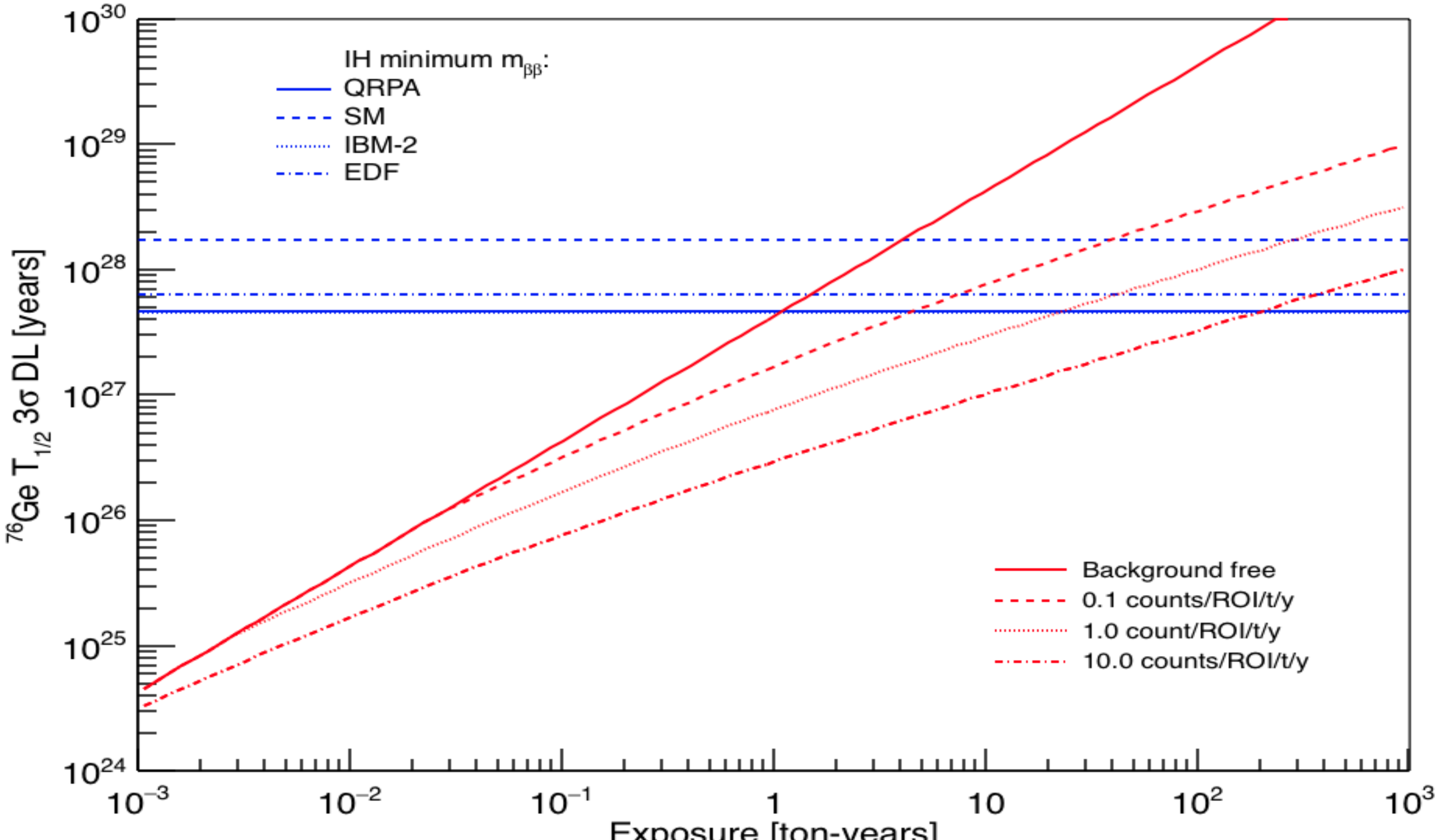
- This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, the Particle Astrophysics and Nuclear Physics Programs of the National Science Foundation, and the Sanford Underground Research Facility. We acknowledge the support of the U.S. Department of Energy through the LANL/LDRD Program.

Backup



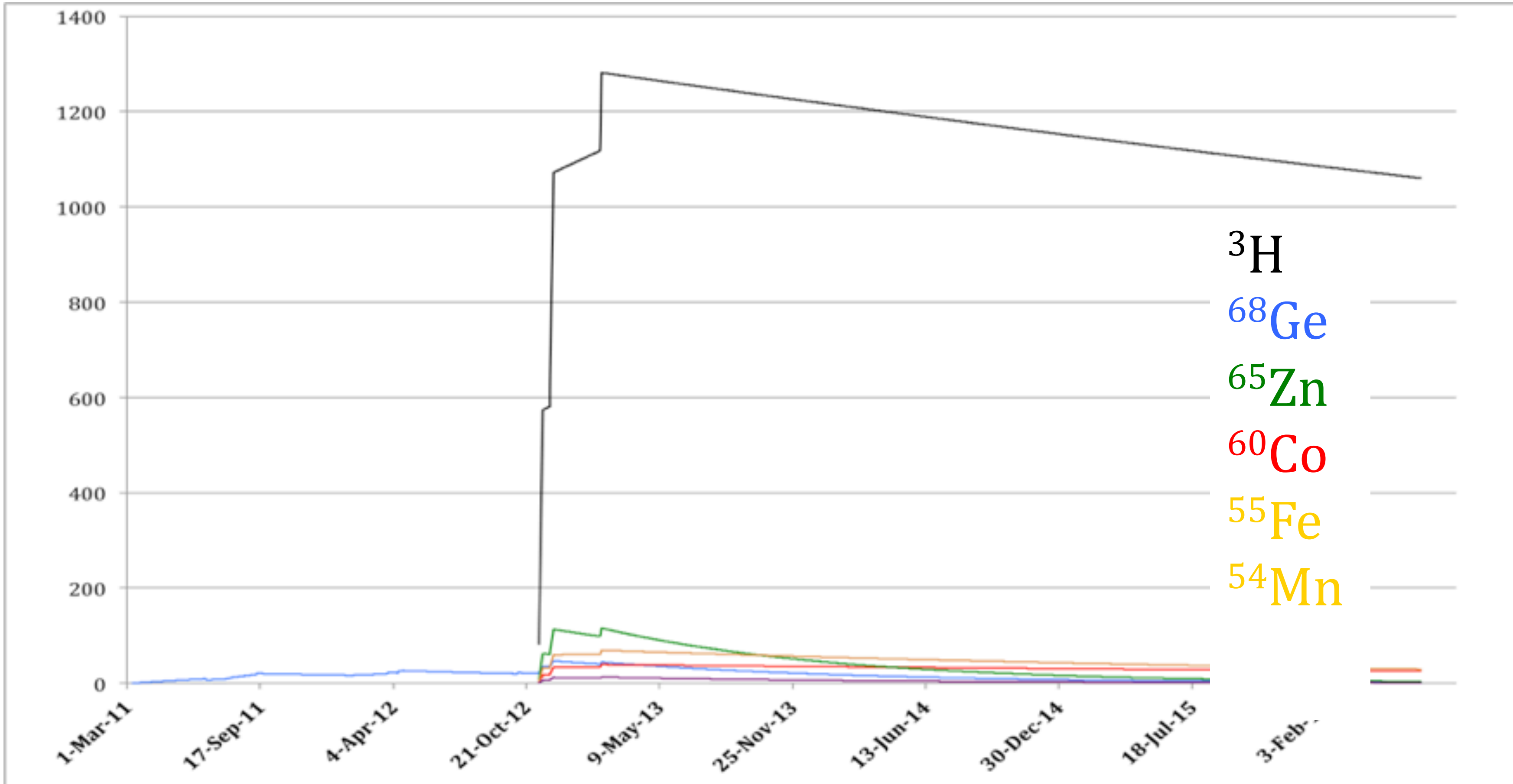
Discovery, Background and Exposure





Isotope Production in Detector P42537A

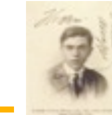
Estimations made from measured cross section and database information.



Typical Effective Sea-level Exposure of Enriched Ge

Location	Days	Cosmogenic Reduction Factor	Sea-level exposure days equivalent
Production and Storage at ECP, Russia	144	22	6.5
Shipping From ECP to Oak Ridge, TN	39	10	3.9
Receiving at ESI, Oak Ridge	0.5	1	0.5
Storage Cherokee Caverns, Oak Ridge	367-412	100	3.6
Reduction at ESI, Oak Ridge	1.5	1	1.5
Zone Refinement (two or three passes)	3	1	3
ORTEC processing	6.5	1	6.5
Delivery from Oak Ridge to SURF, Lead SD	1.5	1	1.5
Total			**27**

Isotope Abundance Estimation



Module 1 detectors July 26th 2016.

Isotope	Atoms per kg
^{54}Mn	$9.9^{+7.8}_{-5.4}$
^{55}Fe	$6.6^{+3.5}_{-2.2}$
^{60}Co	34^{+25}_{-16}
^{68}Ge	$9.5^{+3.8}_{-2.4}$
^{65}Zn	29^{+15}_{-10}
^{3}H	3600^{+1800}_{-1100}