Nuclear Engineering
THE UNIVERSITY OF UTAH

PyNIC: Python-Based Neutron Interaction Calculator for Accurate Activation Predictions in TRIGA Experiments and Student Training

Greg Moffitt, JoCee Porter, Tatjana Jevremovic

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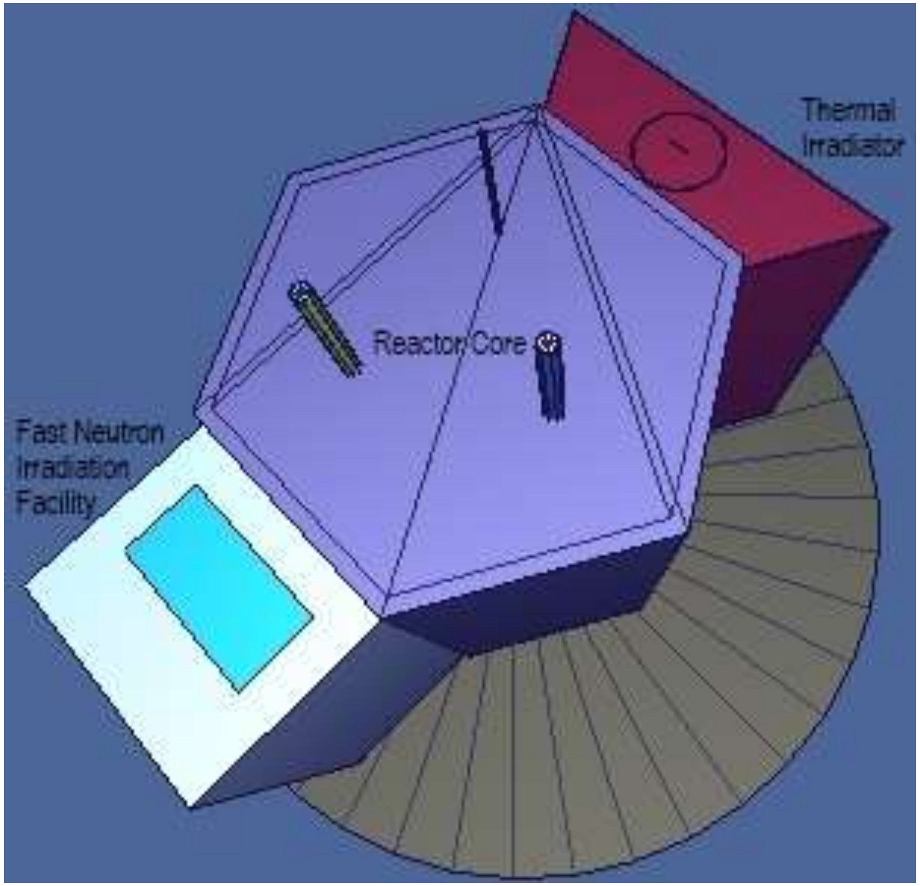
Outline

- NAA at University of Utah TRIGA Reactor
- PyNIC Layout and Use
- TRIGA Reactor Info and Irradiation ports
- MCNP6 Simulations of University of Utah TRIGA reactor
- PyNIC Code Benchmarking
- Future Work

NAA at University of Utah TRIGA Reactor

- Neutron activation analysis (NAA) is performed in the University of Utah TRIGA reactor (UUTR) for a wide range of samples
  - Part of student training and student research
- Accurate pre-calculations leads to safe irradiations where dose is limited and activities are maintained in a range for counting on HPGe detectors



Python-Based Neutron Interaction Calculator (PyNIC)

$$A_D(t) = m\left(\frac{N_A}{A_m}\right)A_{\%}\left(1 - e^{-\lambda_D t_{irr}}\right)e^{-\lambda_D t_{decay}}\int_0^{\infty}\Phi(E)\sigma_p(E)dE$$

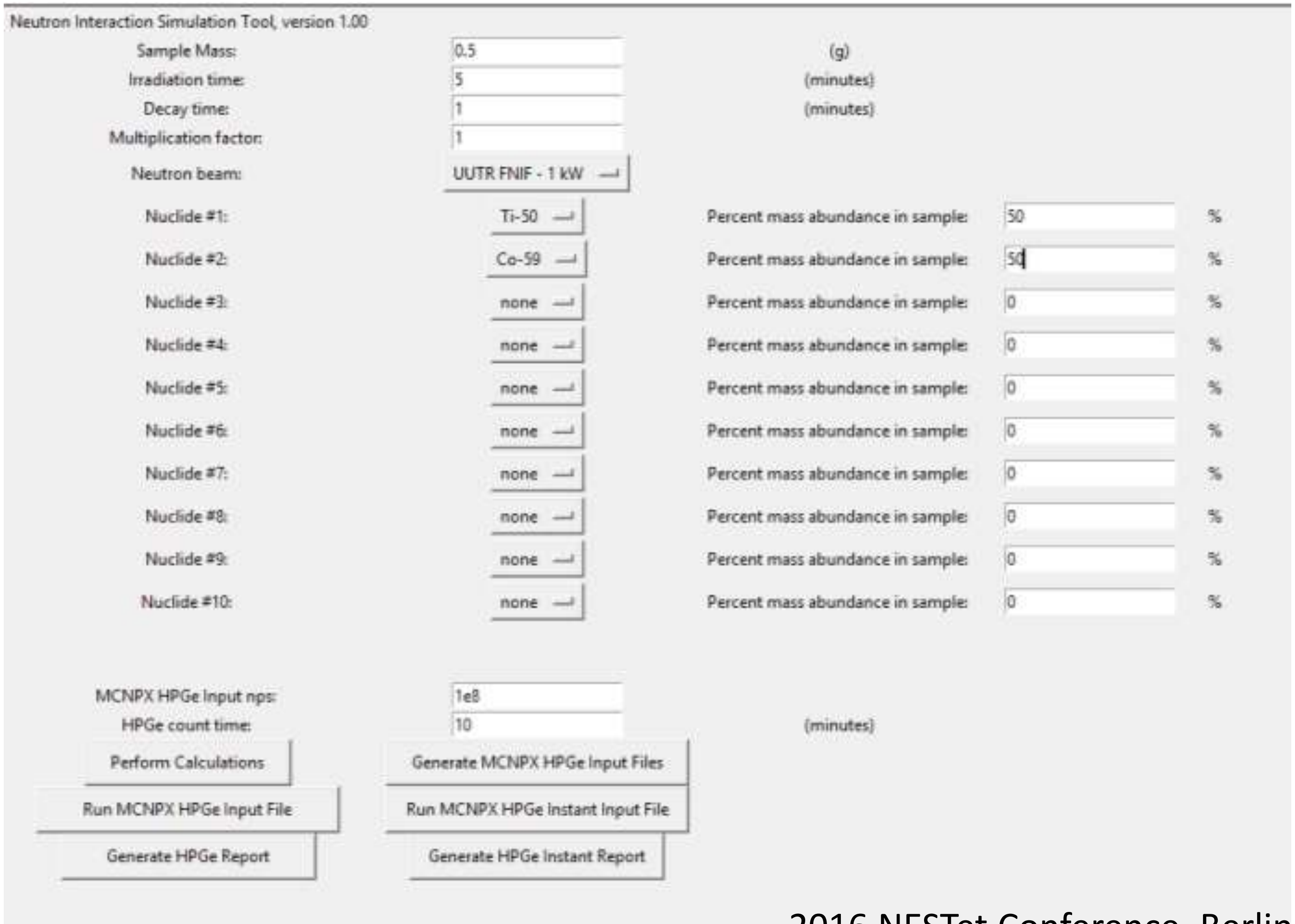
- Entire neutron absorption cross-cross section included for each built-in nuclide
- Calculates the activity
- Calculates the dose rate for γ at 1 ft
- Currently contains 240 nuclides
- Once validated, PyNIC can be applied to any neutron energy spectrum

$\Phi(E)$ – *neutron flux at energy E (n/(cm^2*s)*
σ_p – *radiative capture cross section of parent isotope (cm^2)*
m – mass of sample (g);
N_A – *Avogadro's number;*
A_m – *atomic mass (g/mole),*
$A_{\%}$ - *atomic abundance ratio*
t_{irr} – *irradiation time (sec)*
t_{decay} – *decay time (sec)*
$A_D(t)$ – *activity of daughter isotope (Bq)*
λ_D – *decay constant of daughter isotope (s^{-1})*

PyNIC Input - Irradiation Parameters

- GUI developed to facilitate the use of PyNIC by any user
  - Aids students as they prepare their own NAA irradiations (with final approval by reactor supervisor)
- User enters/selects:
  - sample mass,
  - irradiation time,
  - decay time,
  - neutron beam

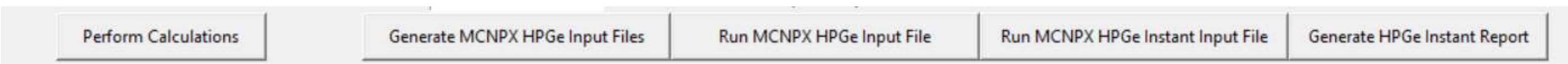
PyNIC GUI


Neutron Interaction Simulation Tool, version 1.00
Sample Mass: 0.5 (g)
Irradiation time: 5 (minutes)
Decay time: 1 (minutes)
Multiplication factor: 1
Neutron beam: UUTR FNIF - 1 kW
Nuclide #1: Ti-50 Percent mass abundance in sample: 50 %
Nuclide #2: Co-59 Percent mass abundance in sample: 50 %
Nuclide #3: none Percent mass abundance in sample: 0 %
Nuclide #4: none Percent mass abundance in sample: 0 %
Nuclide #5: none Percent mass abundance in sample: 0 %
Nuclide #6: none Percent mass abundance in sample: 0 %
Nuclide #7: none Percent mass abundance in sample: 0 %
Nuclide #8: none Percent mass abundance in sample: 0 %
Nuclide #9: none Percent mass abundance in sample: 0 %
Nuclide #10: none Percent mass abundance in sample: 0 %
MCNPX HPGe Input nps: 1e8
HPGe count time: 10 (minutes)
Perform Calculations
Generate MCNPX HPGe Input Files
Run MCNPX HPGe Input File
Run MCNPX HPGe Instant Input File
Generate HPGe Report
Generate HPGe Instant Report

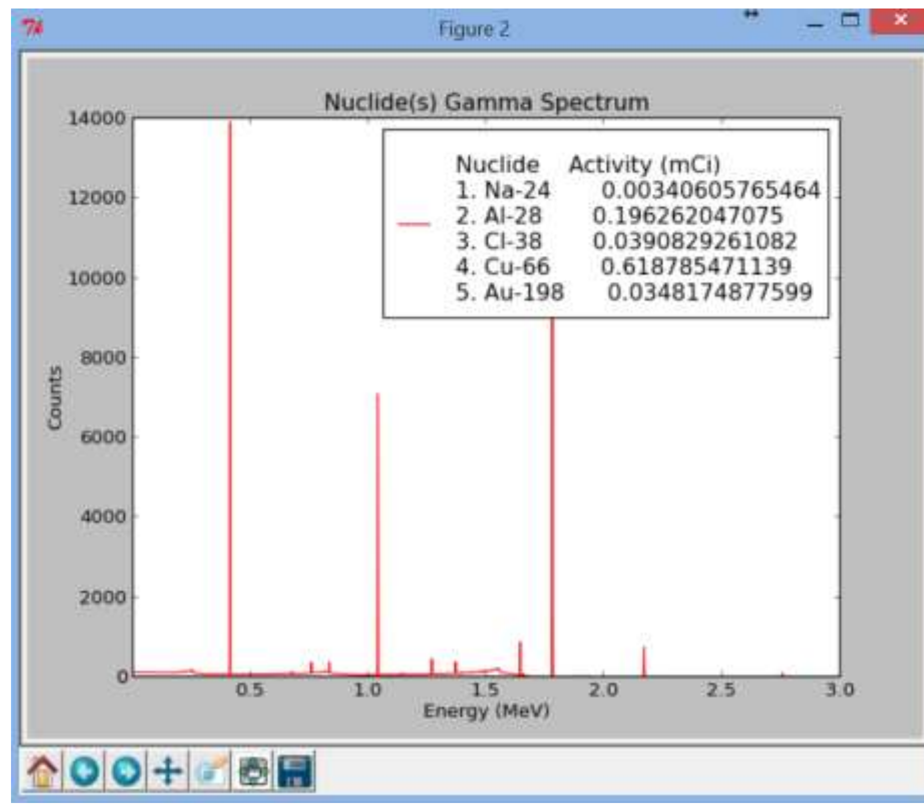
PyNIC: Running Calculations

- Perform Calculations button:
  - Prints activity and dose rate calculations to command prompt
  - Generates a report of activity, dose rate, 5 most abundant gamma emissions from daughter product decay, prompt gamma emission rates and gamma ray energies
  - Result can be used in MCNPX simulation of germanium detector response

PyNIC: MCNPX Gamma Spectrum Simulations

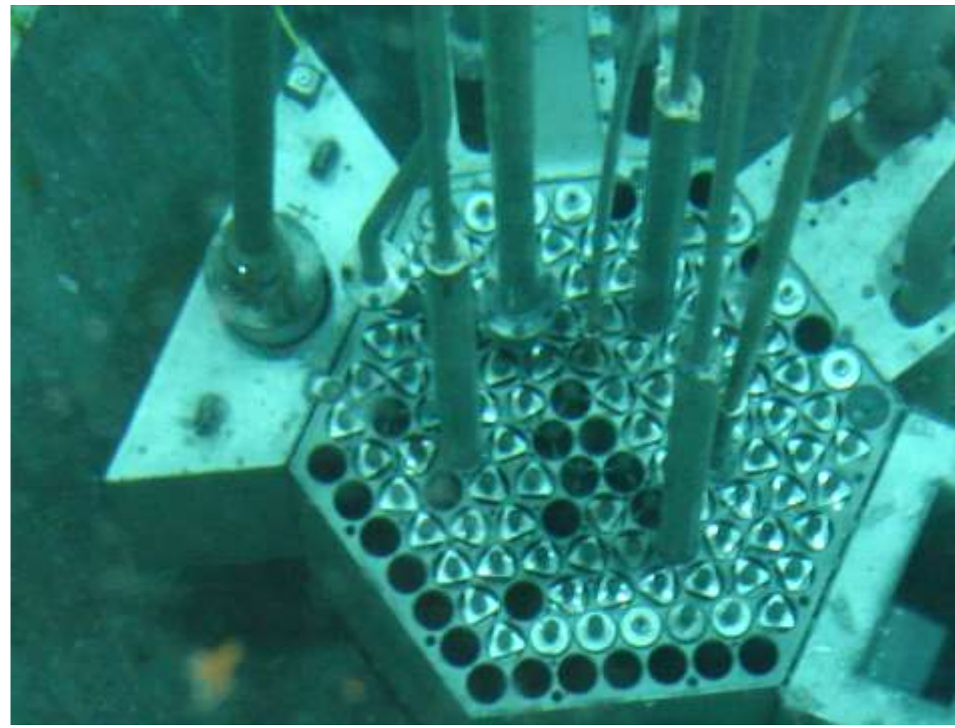


- Generate and run MCNPX HPGe detector input based on the predicted gamma emissions from the activated sample
  - Creates input file
  - Runs file (MCNPX must be installed)
  - Parses MCNPX output file and plots gamma spectrum



UUTR Irradiation Ports

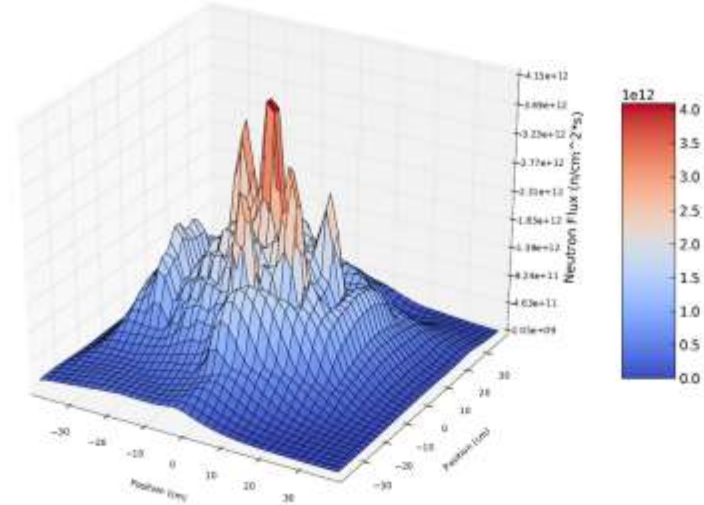
- UUTR (licensed to 100 kW) 4 irradiation ports
  - Thermal Irradiator (TI)
  - Central Irradiator (CI)
  - Pneumatic Irradiator (PI)
  - Fast Neutron Irradiator Facility (FNIF)
- TI flux of $7.3x10^{11}$ n/(cm^2*s)



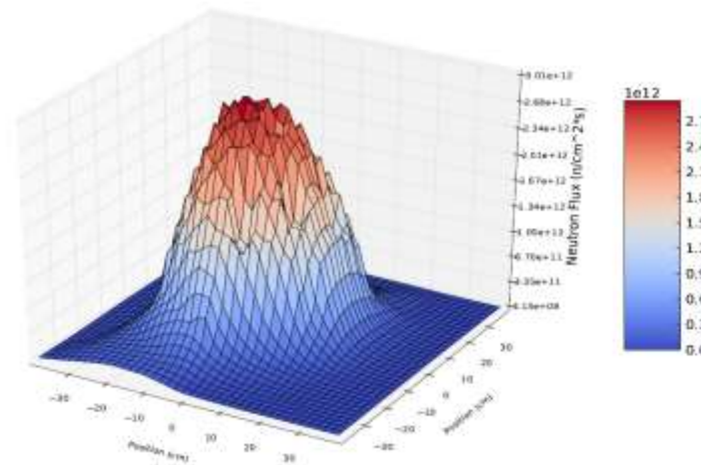
University of Utah TRIGA Reactor

MCNPX Simulation of UUTR

- 2620 neutron fluence tally bins from 0 to 10 MeV for neutron fluence tally (F4:n)
- PyNIC can use any neutron energy bin structure
  - User can make energy bin structure as fine or as course as needed for their application

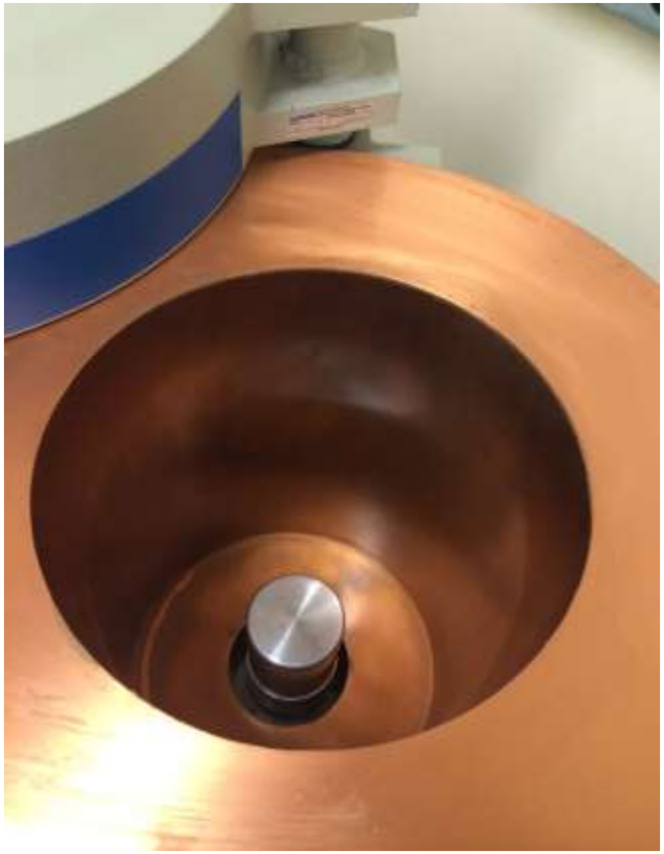


UUTR Thermal Neutron Flux



UUTR Fast Neutron Flux

PyNIC Benchmarking



HPGe detector with Canberra lead and copper shielding

- Samples irradiated in the thermal irradiator port in the UUTR
- Materials irradiated
  - Ni wire
  - Co wire
  - Ti wire
  - W wire
- Samples counted on a HPGe detector

NAA Measurement Results

- Ni and Ti results agree with predictions within +/-8.5% for all points
- PyNIC over predicts the activity for W and Co samples by ~20-30% for most experiments

Material	Reactor Power (kW)	Measured Activity (uCi/g)	PyNIC Activity (µCi/g)	% Difference
Ni	1	0.23	0.25	7.4%
	10	2.8	3.0	8.5%
	30	7.5	7.6	1.6%
	50	13	12	-0.9%
	70	18	18	1.1%
	90	22	23	4.0%
Ti	1	3.7	3.8	-1.4%
	10	39	38	-2.8%
	30	111	114	2.0%
	50	202	189	-6.3%
	70	264	265	0.4%
	90	326	341	4.3%
W	1	1.50	1.20	24.6%
	30	136	104	30.6%
	50	75	74	2.2%
	70	106	84	26.5%
	90	136	106	27.9%
Co	1	6.7	7.7	23.1%
	50	35	39	17.7%
	90	61	70	17.0%

Future Work

- Additional NAA experiments in UUTR
- Add post calculation functionality to get starting material concentration
- Add secondary decay daughter product gamma emissions

Acknowledgements

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