Fingerprinting of the commercial nuclear reactor forensics using Origen-S modeling code

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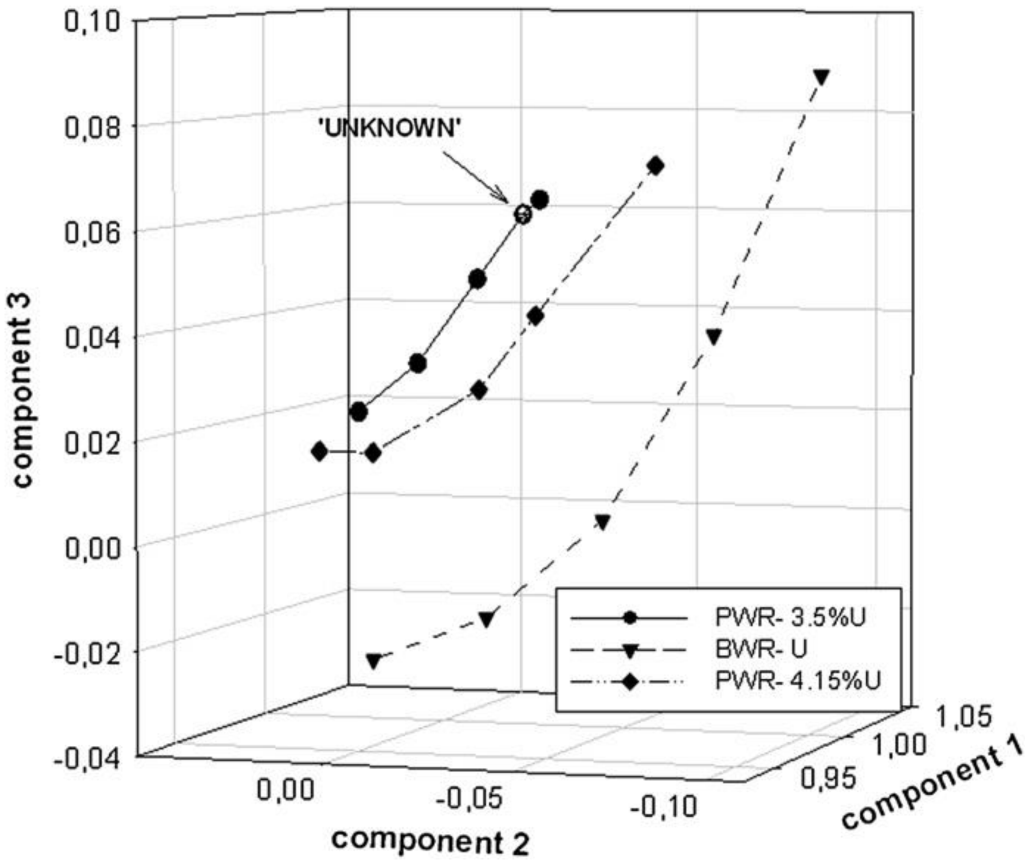
Outline

- Introduction
- Motivation and Limitation
- Origen-S Modelling Code
- Simulation and Results
- Discussion and Future Prospects

Introduction

- **Nuclear Forensics is the technical means by which nuclear materials are characterised and interpreted**
- **Nuclear forensics helps counter smuggling of nuclear materials that could be used in an attack**
- **G. Nicolaou (*Journal of Environmental Radioactivity 86 (2006) 313 – 318; 99 (2008)1708 – 1710*) studied different reactor types using Origen-2, which is outdated and lack the proper nuclear data to make accurate isotopic predictions**

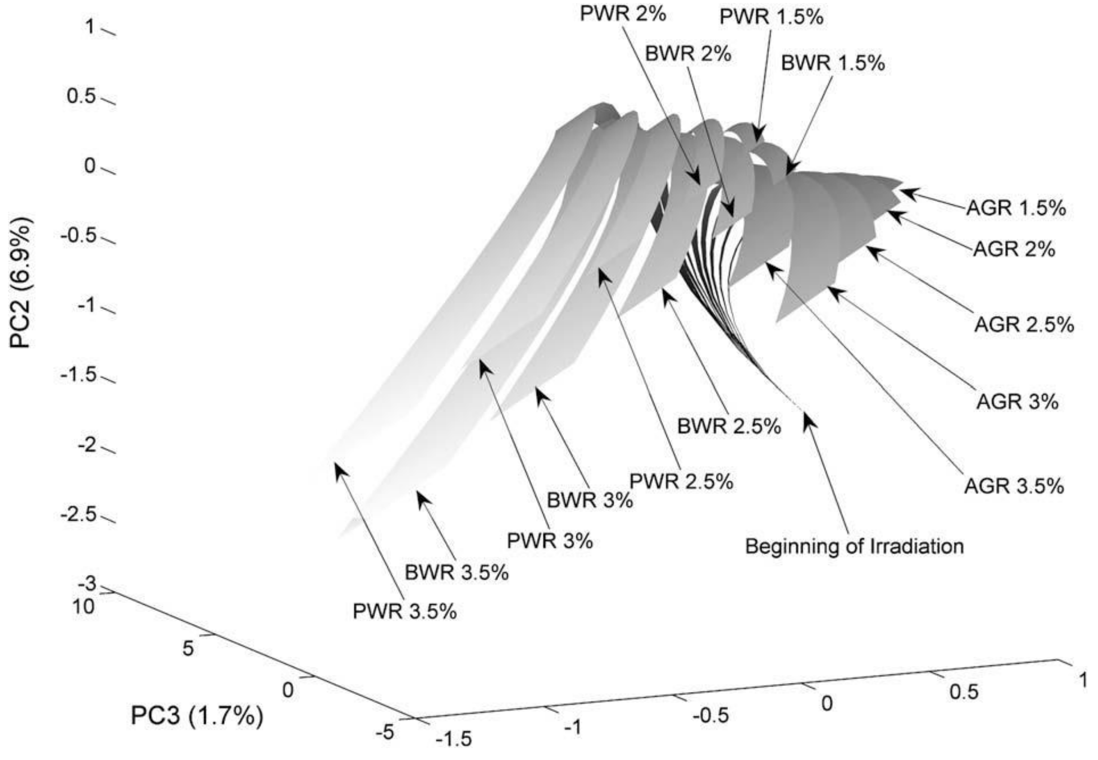


3D plots from the factor analysis showing the similarities between the simulated PWR, BWR and the 'unknown'.

Introduction

- **However, Robel et al (*Journal of Environmental Radioactivity 99 (2008) 1789-1797*) used Origen-S and Principal Component Analysis (PCA) to quantify the composition of U and Pu isotopes in fuel as a function of burnup.**

- **Focused on the fuel initial enrichment averaged across an entire core loading and the irradiation time of the fuel**



PCA of Pu isotopes only. All reactor type–fuel combinations are well resolved starting very early in core life. All start at a common point corresponding to zero Pu concentration.

Motivations

- Identify the reactor characteristics necessary to connect spent fuel to a particular reactor of the same type
- Implement the isotopic composition of U and Pu spent fuel to predict fuels from the same reactor type, e.g. 17X17 Westinghouse PWR
- Important signature for determination of the origin of “unknown” seized nuclear materials

Limitations

- Limited access to centralized international nuclear-forensic database
- Data characterizing nuclear materials and processing histories are sensitive and may be classified
- Sensitivities can be commercial (in the case of nuclear fuels) or security-related (for weapons-grade uranium or plutonium)

ORIGEN-S Modelling Code

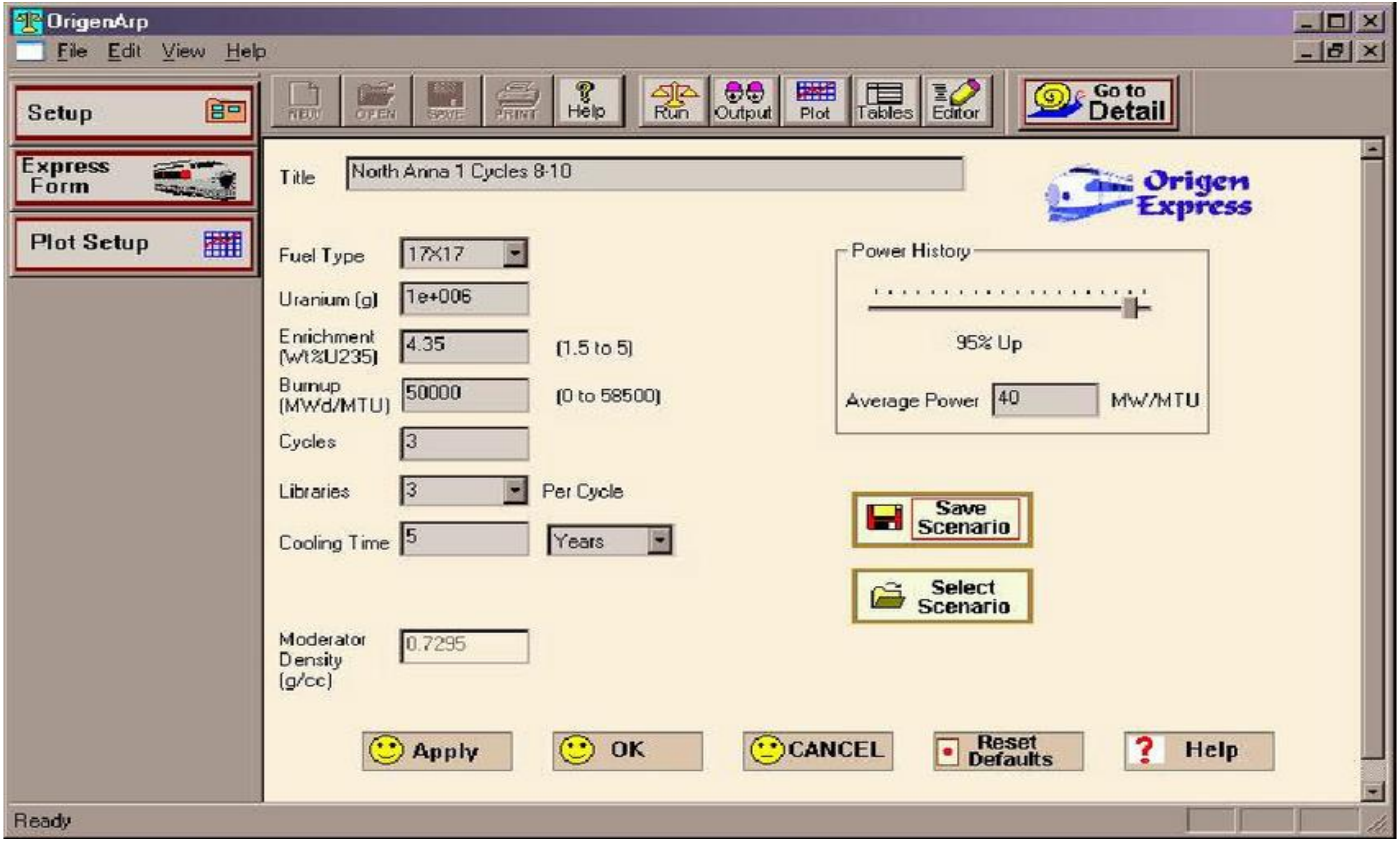
- ORIGEN code are used for calculating Depletion, Decay, and Radioactive Source Term Analysis

- ORIGEN code applies a matrix exponential expansion model to calculate time-dependent concentrations, activities, and radiation source terms for a large number of isotopes simultaneously generated or depleted by neutron transmutation, fission and radioactive decay

- ORIGEN includes the ability to utilize multigroup cross sections processed from standard ENDF/B evaluations.

- An alternative sequence for depletion/decay calculations is ORIGEN-ARP, which interpolates pre-generated ORIGEN cross-section libraries versus enrichment, burnup, and moderator density.

ORIGEN-ARP


OrigenArp
File Edit View Help
Setup
Express Form
Plot Setup
Help
Run
Output
Plot
Tables
Editor
Go to Detail
Title
North Anna 1 Cycles 8-10
Origen Express
Fuel Type
17X17
Uranium (g)
1e+006
Enrichment (Wt%U235)
4.35
(1.5 to 5)
Burnup (MWd/MTU)
50000
(0 to 58500)
Cycles
3
Libraries
3
Per Cycle
Cooling Time
5
Years
Moderator Density (g/cc)
0.7295
Power History
95% Up
Average Power
40
MW/MTU
Save Scenario
Select Scenario
Apply
OK
CANCEL
Reset Defaults
Help
Ready

Simulation Input Parameters

Overview of the characteristics of Commercial Nuclear Reactors Westinghouse 17x17 Fuel Assembly

Reactor	Electrical Output (MWe)	Fuel Enrichment (%)	Burn Up (GWd/MTU)	Fuel Cycle (months)	Power History (%)
Comanche Peak 1	1209	4.0	40	18	91
North Anna 1	903	2.8	39	18	78
Indian Point 2	1022	4.1	36	24	98
Seabrook Station 1	1080	3.57	33	12	77

Results I: Uranium Isotopic Concentration

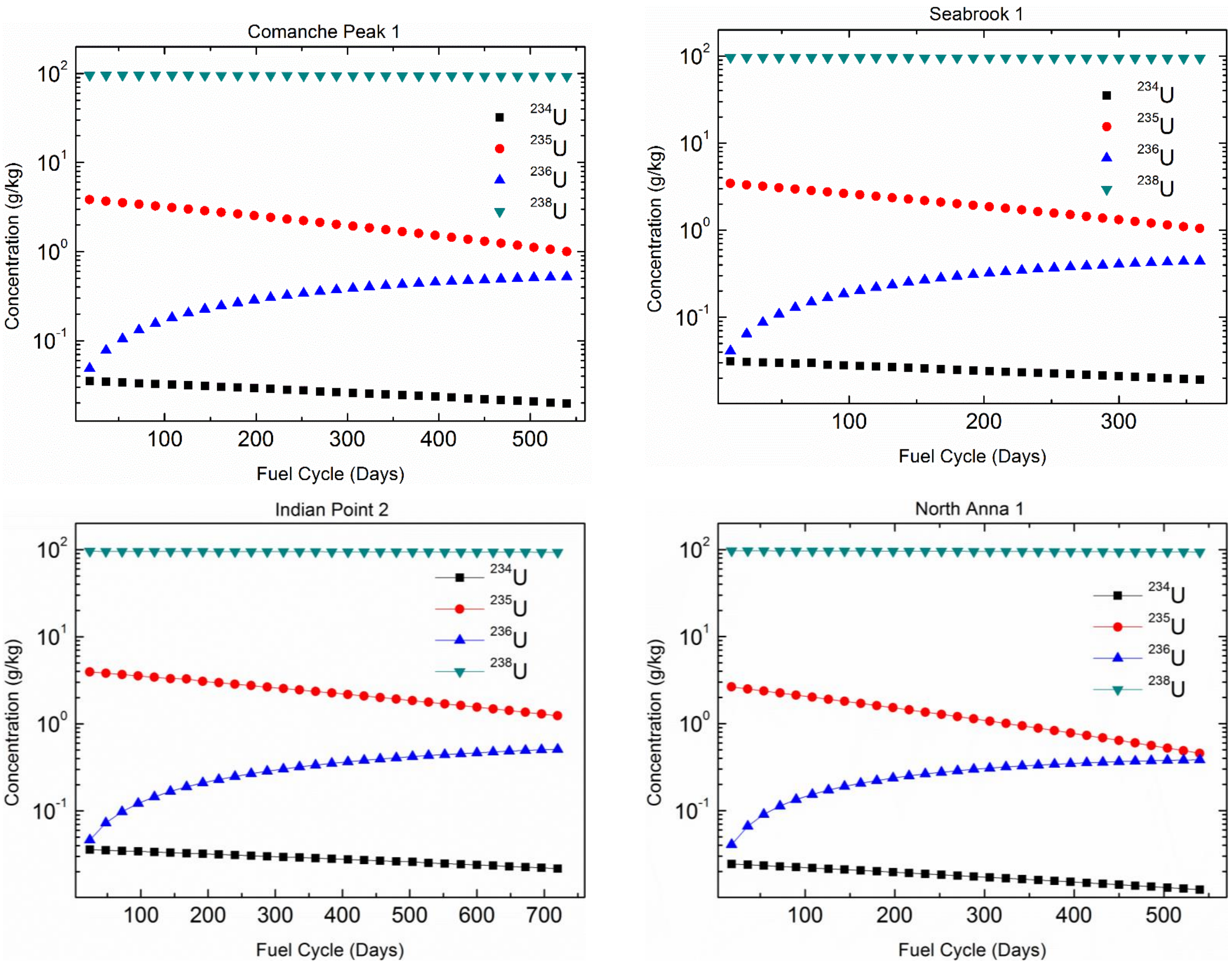


Figure showing the concentration of uranium isotopic content during the fuel cycle period and End of Irradiation (EOI).

- **This provides information on the enrichment of "unknown" spent fuel.**

- **^{236}U produced through transmutation of ^{235}U which varies in different reactors**

Results II: Plutonium Isotopic composition

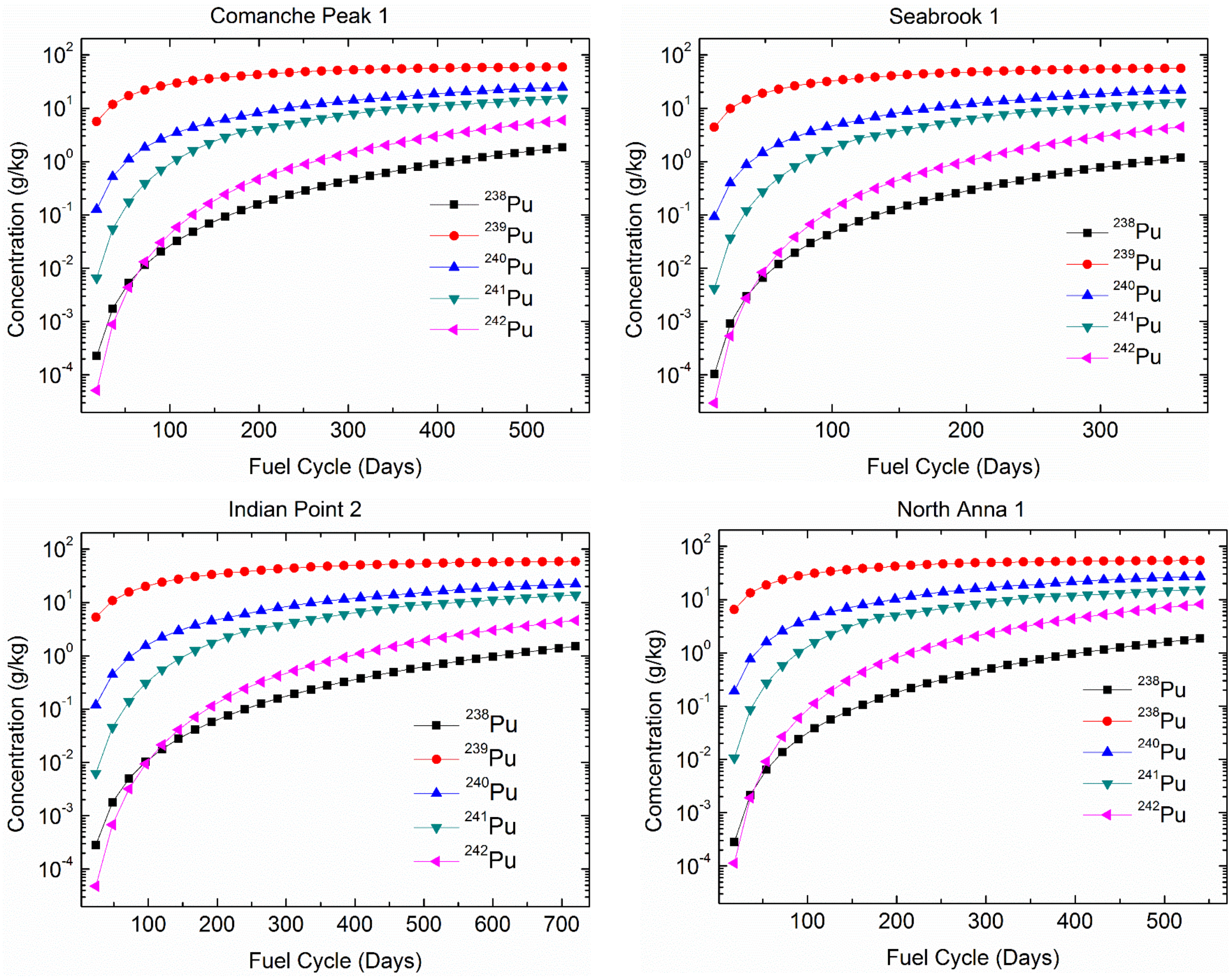
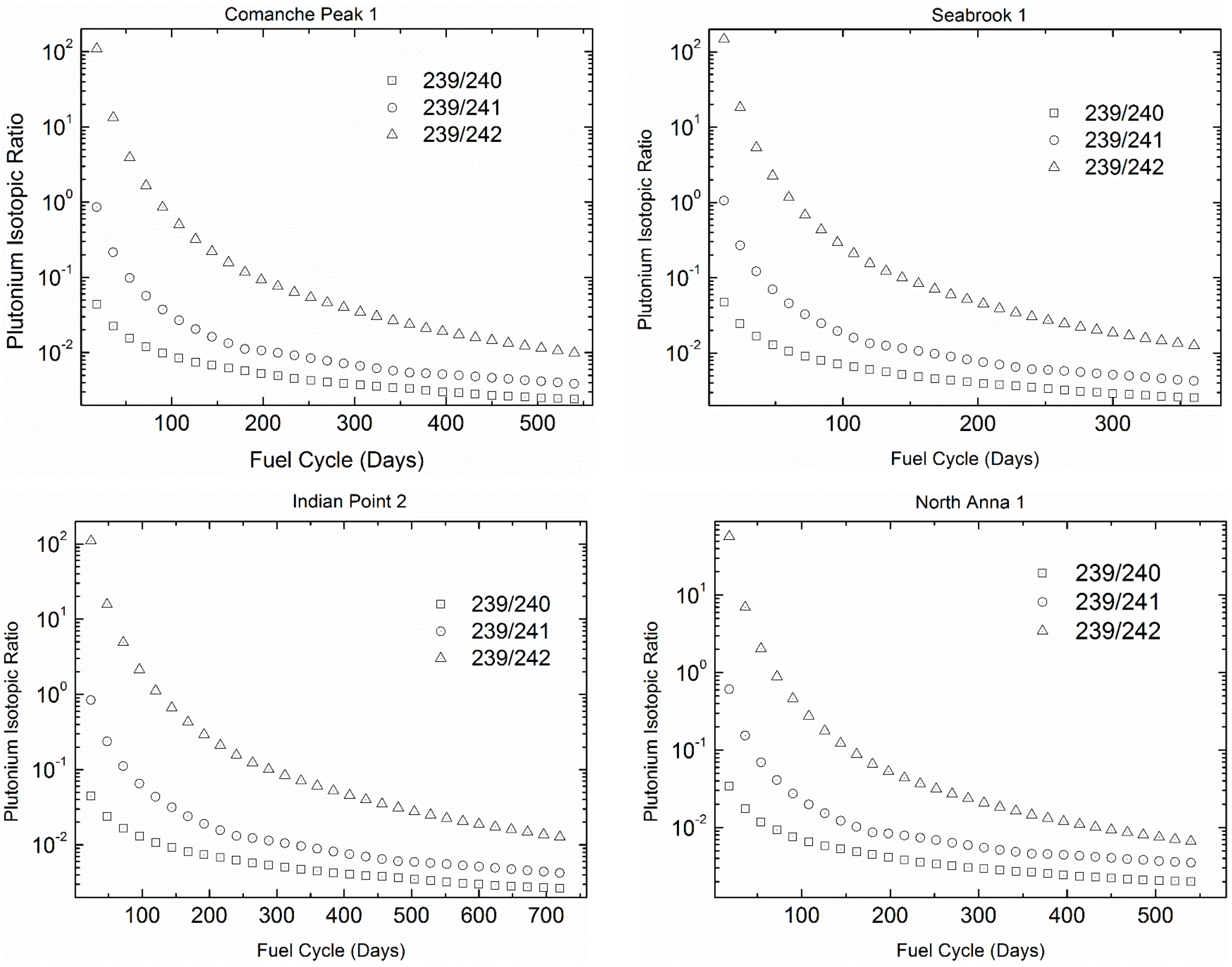


Figure showing the concentration of plutonium isotopic content during the fuel cycle period and End Of Irradiation (EOI).

Results III: Plutonium Isotopic Ratio



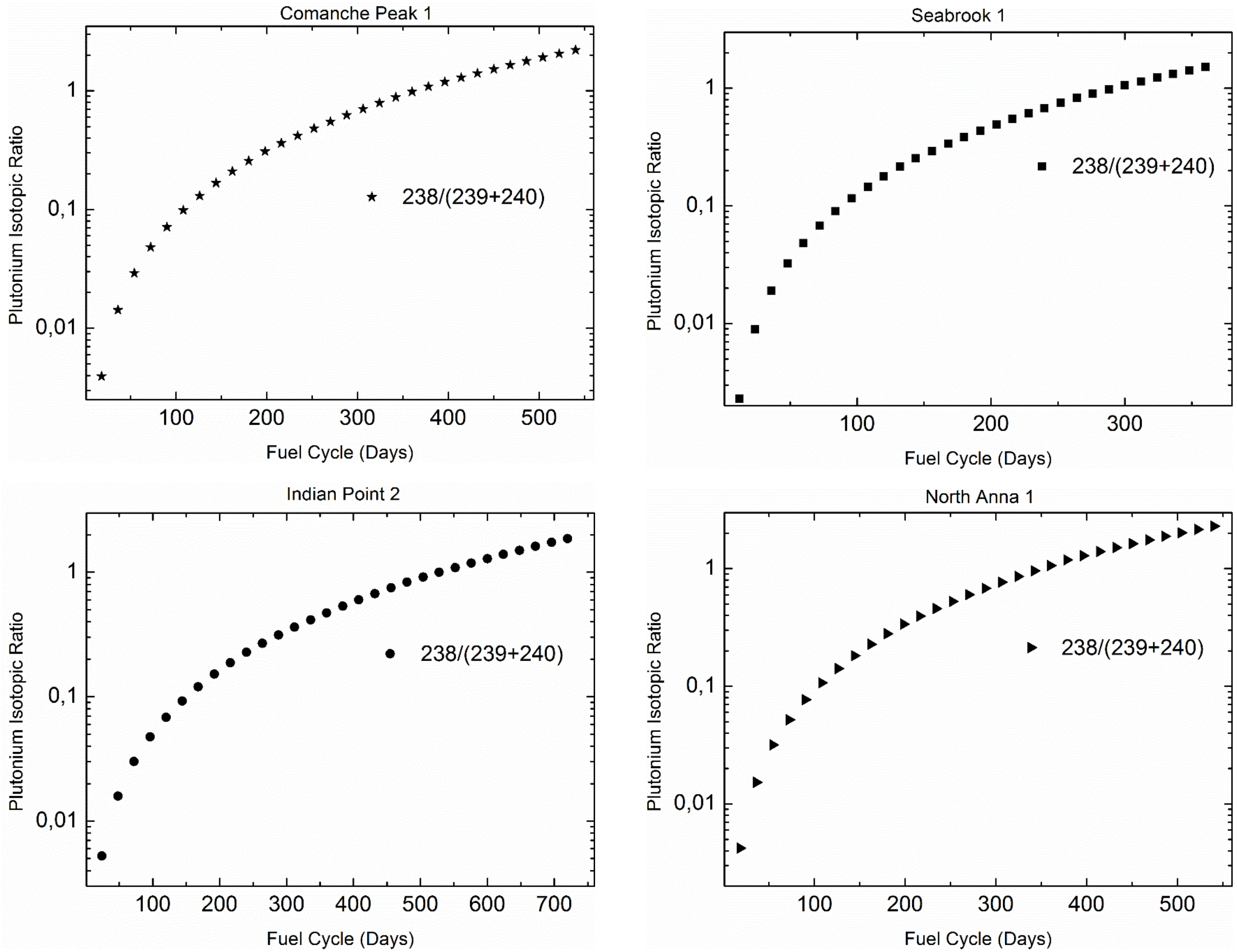
- **Figure showing the isotopic ratio of plutonium in nuclear reactors during the fuel cycle period and EOI.**

Neutron Flux (neutrons/cm^2-sec)

Comanche Peak (8.86 x 10^{13})
Indian Point (5.68 x10^{13})
North Anna (1.13 x10^{14})
Seabrook (1.15 x10^{14})

- **Depletion of ^{241}Pu due to β^- decay to ^{241}Am ($T_{1/2} = 14.9\,Y$)**

Results IV: Plutonium Isotopic Ratio



- **Figure showing the isotopic ratio of plutonium in nuclear reactors during the fuel cycle period and EOI.**
- **Build-up of ^{238}Pu from α-decay of ^{242}Cm ($T_{1/2} = 163\ d$)**

Discussion

- It can be deduced that the ^{239}Pu has the highest atomic concentration among the other isotopes present while ^{238}Pu gives the lowest concentration in all cases considered.

- Isotopic ratios of Plutonium (239/240, 239/241/ and 239/242) provided information on the neutron flux.

- ^{234}U natural abundance varies slightly in uranium ore due to a combination of nuclear decay, chemical and hydrologic factors.

Outlook

- Extend to other types of reactor => BWR, VVER, AGR and CANDU
- Set up Signature/Attribution Database for all types of Generation II power reactor
- Complimentary experimental measurements using analytical techniques
- Signature Database for Uranium Oxides originating from mines in African countries such as South Africa, Namibia, Niger and Gabon.

Acknowledgements

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Ευχαριστώ

Overview of the characteristics of Commercial Nuclear Reactors

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Comanche Peak 1	1209	4.0	40	18	91
North Anna 1	903	2.8	39	18	78
Donald Cook 1	1009	3.35	38	18	87
Indian Point 2	1022	4.1	36	24	98
Seabrook Station 1	1080	3.57	33	12	77
McGuire 1	1100	3.75	40.2	12	94
Diablo Canyon 1	1122	4.2	45	18	100
Shearon Harris 1	1126	3.8	31.5	18	100
Catawba Nuclear 1	1129	3.75	40.2	13	89
Vogtle 1	1150	3.6	36.4	18	92
Sequoyah 2	1152	4.0	45	18	89
Braidwood Station 2	1152	3.55	33	18	93
Wolf Creek 1	1160	3.8	33	18	72
R.E.Ginna 1	1174	3.7	39	12	84
Prairie Island 1	1185	4.95	49.5	20	91
Callaway 1	1190	3.6	42	18	90