Australia's Experience in the Galaxy Serpent Table Top Exercise

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Introduction:

Australian Nuclear Science and Technology Organisation (ANSTO) National Security Research Program staff participated in the International Technical Working Group on Nuclear Forensics (ITWG) Galaxy Serpent National Nuclear Forensics Library (NNFL) Table Top Exercise.

Method:

We established a "Virgo Galaxy" NNFL using three isotopic datasets (named Anthea-PWR, Atlas-BWR and Enceladus-BWR) and compared an unknown (Clio) with the NNFL (using Microsoft Excel and Multivariate Analysis).

Results:

We determined that the Clio material was unlikely to have originated from our Galaxy.

Table 1. Extracted example of the Anthea-PWR raw data supplied as part of the TTX

No	Data Type	Cooling Year	Values	1 sigma uncertainty	Unit	Uncertainty (% 1 sigma)
1	Am-241	6.7	0.377	0.018473	kg/MTU initial	4.90
2	Am-241	6.7	0.679	0.033271	kg/MTU initial	4.90
55	Pu-238/Total Pu(RateOfWeight)	6.7	0.0196	0.00044296	None	2.26
56	Pu-238/Total Pu(RateOfWeight)	6.7	0.0326	0.00073676	None	2.26
440	burnup(by Nd-148 method)	6.7	46.5	1.1625	GWD/MTU	2.50
441	burnup(by Nd-148 method)	6.7	37.3	0.9325	GWD/MTU	2.50

Table 2. Extract of Isotopic correlations available from Virgo Galaxy reactors

Reactor	Sample number	U235% / U-236%	(Np-237/ U236)/ U-235%	(Pu/U238)/U235%	U235%/(Pu/U)
Anthe-PWR	1	1.347692308	0.200913242	0.019732891	51.10851809
	2	0.463768116	0.731884058	0.065831557	15.23809524
	3	0.89244186	0.331414287	0.030667225	32.8342246
Atlas-BWR	1	1.511221945	0.160901377	0.013940148	72.48803828
	2	4.530201342	0.043251305	0.004783467	212.5984252
	3	1.333333333	0.168717921	0.014759553	68.4144819
Unknown Clio-1	1	3.042896608	0.056679288	0.00484989	209.3833343
Unknown Clio-2	2	1.250392855	0.156975926	0.012935539	78.12343555
Unknown Clio-3	3	0.904797384	0.225616535	0.01880911	53.64692536
Unknown Clio-4	4	1.802190937	0.102894731	0.008253987	122.6554573

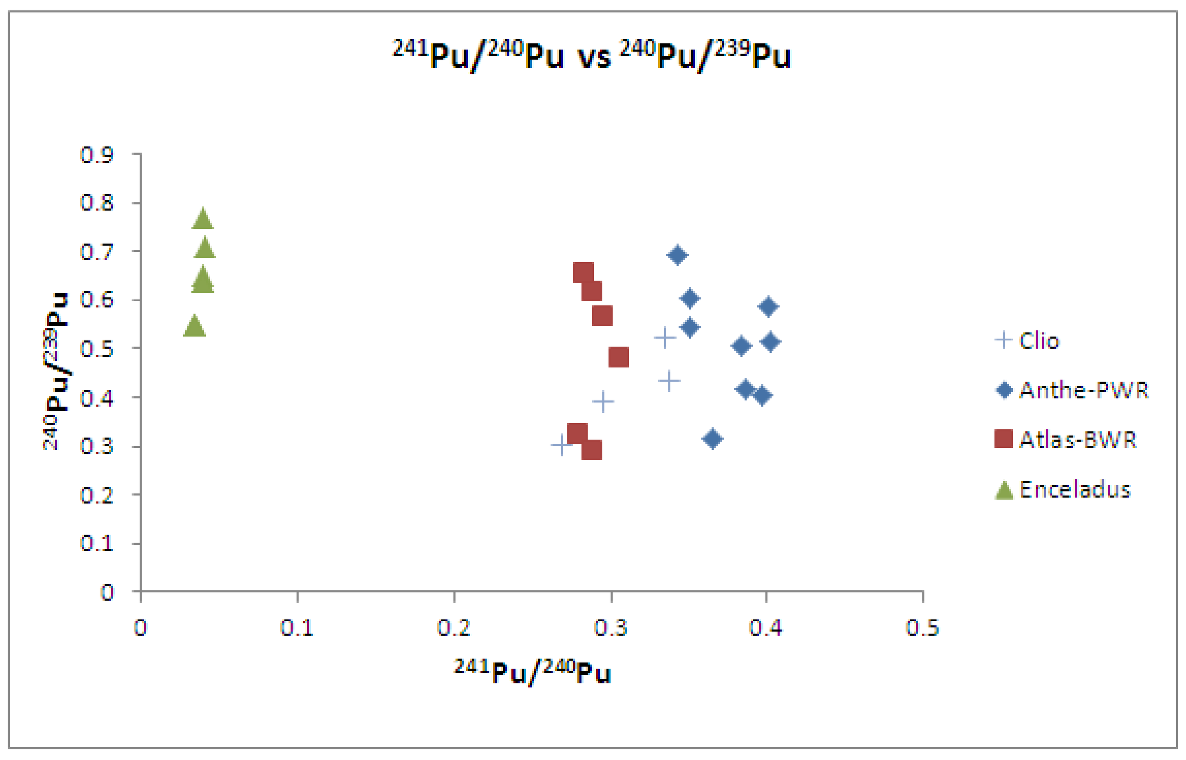

Figure 1. The isotopic correlation $^{241}Pu/^{240}Pu$ vs $^{240}Pu/^{239}Pu$ comparing "Virgo Galaxy's" three reactors to the intercepted Clio sample

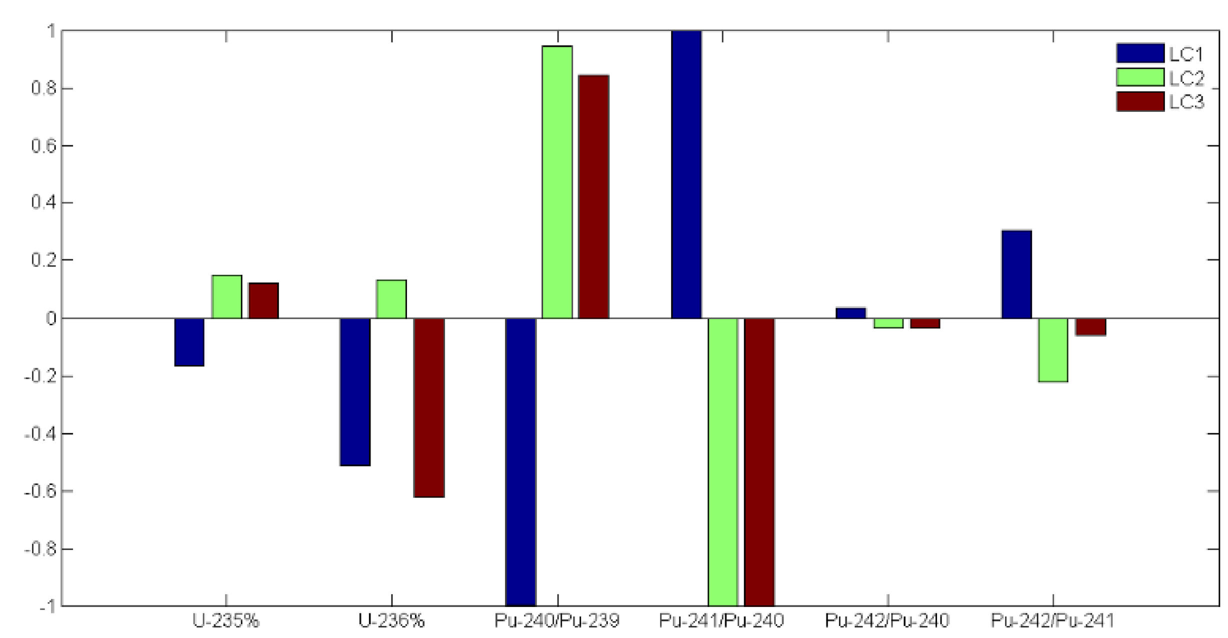

Figure 2. Fisher Linear Discriminant Analysis (FLDA) loading co-efficients of the $^{235}U\%$, $^{236}U\%$, $^{240}Pu/^{239}Pu$, $^{241}Pu/^{240}Pu$, $^{242}Pu/^{240}Pu$ and $^{242}Pu/^{241}Pu$ data types between the three reactors and intercepted sample Clio

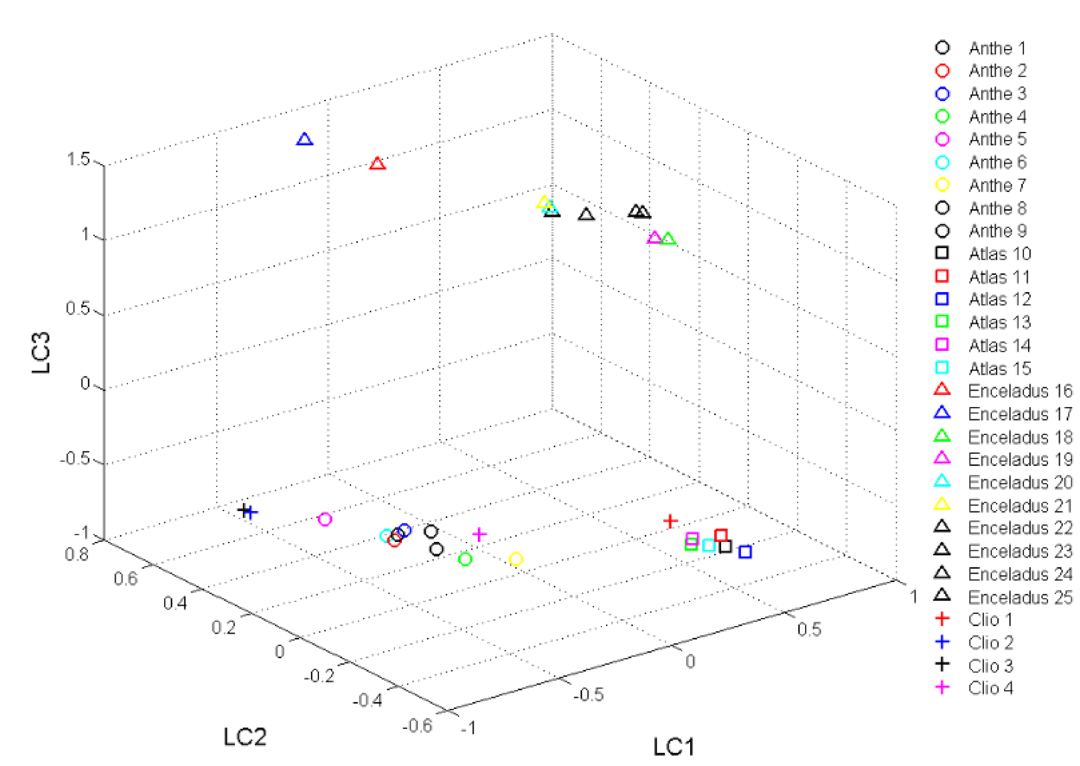

Figure 3. FLDA of the $^{235}U\%$, $^{236}U\%$, $^{240}Pu/^{239}Pu$, $^{241}Pu/^{240}Pu$, $^{242}Pu/^{240}Pu$ and $^{242}Pu/^{241}Pu$ data types between the three reactors and intercepted sample Clio

Table 3. A summary of the data types used in each statistical analysis to determine whether the intercepted sample Clio matched a reactor from the Virgo Galaxy

Data types analysed	Analysis tool	Clio data match to: Anthea-PWR data	Atlas-BWR data	Enceladus-BWR data
^{235}U (%wt), ^{238}U (%wt), $^{240}Pu/^{239}Pu$, $^{241}Pu/^{240}Pu$, $^{242}Pu/^{240}Pu$, $^{242}Pu/^{241}Pu$	FLDA	Suggestive positive	Suggestive positive	Conclusive negative
$^{241}Pu/^{240}Pu$ vs $^{240}Pu/^{239}Pu$	MS Excel	Inconclusive	Suggestive positive	Conclusive negative
All provided isotopes (% wt)	FLDA	Suggestive positive	Suggestive negative	Not analysed
Plutonium ratios, total Pu/^{238}U, total Pu/total U, $^{99}Tc/U$, ^{241}Am/total U, ^{237}Np/total U, $^{237}Np/^{236}U$, $^{236}U/^{238}U$	FLDA	Inconclusive	Suggestive negative	Not analysed
All isotopic correlation datasets	FLDA	Inconclusive	Inconclusive	Not analysed
> 0.1% of transuranic elements	FLDA	Inconclusive	Inconclusive	Not analysed
Amounts of indivudal isotopes in kg/MTU, burnup of isotopes in GWD/MTU, isotopic ratios	FLDA	Inconclusive	Inconclusive	Not analysed

Conclusions:

1. An NNFL can be readily generated using common software (such as Microsoft Excel).
2. If available, multivariate analysis (MVA) techniques can provide additional insight to Excel analysis.
3. SI units should be used to aid communication between stakeholder groups (e.g. nuclear engineers and forensic scientists).
4. In this study we compared averaged reactor fuel data with individual fuel pellet data. This may not reflect real world experience.
5. The experimental results from this study showed that the 'unknown' was a suggested negative match (unlikely) to have come from any of the reactors included in the Virgo Galaxy NNFL.

Table 4. Isotopes of interest for establishing a National Nuclear Forensics Library – example from the papers appendix

Isotope	Significance Fissile, Fissionable, Fertile, stable Natural abundance Created by… fission of… Unique characteristics/ comments
^{235}U	Fissile Natural abundance 0.72 % Enrichment level depends on application. For example: Conventional enriched power reactor fuel contains 3-5% ^{235}U Low enriched Uranium (LEU) < 20% ^{235}U High enriched Uranium (HEU) > 20% ^{235}U
^{236}U	Weakly fertile Natural abundance: < $1x10^{-10}$ % Generated by ^{235}U (n,g) An effective burn up marker in nuclear forensic applications as it is not fissile and is weakly fertile. With supporting data, can be used to indicate initial U-235 enrichment in irradiated fuels.
^{238}U	Fertile and fissionable Natural abundance: 99.2745% Captures a neutron and becomes (indirectly) ^{239}Pu
^{238}Pu	Fertile and fissionable Generated by ^{238}Np (beta decay), ^{239}Pu (n, 2n) and ^{242}Cm (alpha decay) Relatively low yield in power reactors compared to other Pu isotopes
^{239}Pu	Fissile Generated by ^{239}U beta decay to ^{239}Np, then beta decay to ^{239}Pu Characteristic marker of fluence received in a reactor
^{242}Pu	Fertile and fissionable Generated by ^{242}Pu (n,g) Characteristic marker of large amounts of fluence received in a reactor
^{241}Am	Fissile Generated by ^{241}Pu (beta decay), Under neutron irradiation, ^{241}Am readily captures neutrons and transforms to ^{242}Am. In a stable environment, the weight % of ^{241}Am builds up steadily over time, consequently it is a characteristic marker of how long material has been out from a fissile environment.
^{137}Cs	Fission product ~6.3% fission yield from ^{235}U May be used as a burnup indicator for fuel elements working at relatively low temperature (<500°C) Short term heat emissions caused by ^{137}Cs in spent fuel is a limiting factor for geological storage A commonly used radioisotope in industrial applications and medical therapy to treat cancer
^{237}Np	Fissile Long-lived isotope, half-life of 2 million years considered as waste "bottle neck" Produced in the nuclear reactor from neutron irradiation of ^{235}U and ^{238}U Can be used in nuclear fission reactions and has similar critical mass as ^{235}U About 4-5% of ^{237}Np is found in spent nuclear fuel as Pu discharge
^{90}Sr	Fission product May be used as a burnup indicator for fuel elements working at relatively low temperature (<500°C) Short term heat emissions caused by ^{90}Sr in spent fuel is a limiting factor for geological storage A huge amount produced during nuclear weapon testing Used as a radioactive tracer in medical and agriculture studies
^{99}Tc	Fission product Short-lived parent ^{99m}Tc is a widely use radioisotope in medical diagnostic applications