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INDIVIDUAL FISSION PRODUCTS PRODUCED IN HIGH-EXPOSURE, GAS-COOLED THORIUM REACTOR FUEL

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ABSTRACT

Calculation of the production of individual fission products and fission elements in the ESADA high temperature, gas-cooled graphite-, thorium-, uranium-, fueled reactor are presented. The results indicate that the most important fission produced elements (or groups) are as follows: rare earths, zirconium, molybdenum, xenon, cesium, and ruthenium.

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INTRODUCTION AND SUMMARY

Reactor fuels which have received very high exposures (up to 100,000 Mwd/metric ton) will not only have high concentrations of radioactive fission products, but will also have very much higher concentrations of the non-radioactive species of the same elements. In some cases it may be possible to produce such large quantities of certain fission elements that feed concentrations may be limited by the solubility limits of these elements. In order to obtain some idea of what these production rates are, calculations of the buildup of selected fission products in the General Atomics ESADA reactor were made. The ESADA reactor is a high-temperature, gas-cooled, graphite-, thorium-, uranium-fueled reactor.

The results of the calculations indicate that the most important fission produced elements (or groups) are as follows: rare earths, zirconium, molybdenum, xenon, cesium, and ruthenium.

DISCUSSION

The calculations were made for the ESADA reactor core having the following concentrations and exposures:

Burnup - 84,000 Mwd/metric ton fuel
Irradiation time - 1800 full power days
Specific power - 46.7 Mw/metric ton fuel
Fissions - 1.38 fissions per initial fissile atom
C/Th ratio - 200
C/U ratio - 2750

Composition

	Initial	Final
$^{233}Pa/^{232}Th$	--	1.7×10^{-3}
$^{233}U/^{232}Th$	--	2.47×10^{-2}
$^{234}U/^{232}Th$	--	5.55×10^{-3}
$^{235}U/^{232}Th$	6.8×10^{-2}	7.32×10^{-3}
$^{236}U/^{232}Th$	--	1.10×10^{-2}
$^{238}U/^{232}Th$	4.7×10^{-3}	3.78×10^{-3}

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Figure 1 shows the effect of irradiation time on isotopic concentrations of the important heavy isotopes or gross fission products in the ESADA reactor. The points at 1800 days (full power) are General Atomic calculations. Because of the reasonable agreement between our calculations and those of GA, we feel that the individual fission products should also be reasonable. The agreement for fissile materials and gross fission products were within 6%.

The individual fission products or fission elements are given in Tables 1 through 3.

The flux and cross-section relationships supplied by S. Jaye[1] of General Atomic are as follows:

$$\int \sigma_f^{233U}(E)\ \phi(E)\ dE = 1.613 \times 10^{16} \frac{b}{cm^2\ sec}$$

$$\int \sigma_f^{235U}(E)\ \phi(E)\ dE = 1.272 \times 10^{16} \frac{b}{cm^2\ sec}$$

$$\int \phi(E)\ dE = 1.862 \times 10^{14} \frac{1}{cm^2\ sec}$$

$$\int \sigma^{233Pa}(E)\ \phi(E)\ dE = 5.34 \times 10^{15} \frac{b}{cm^2\ sec}$$

$$\int \sigma^{234U}(E)\ \phi(E)\ dE = 6.03 \times 10^{15} \frac{b}{cm^2\ sec}$$

$$\int \sigma^{236U}(E)\ \phi(E)\ dE = 2.18 \times 10^{15} \frac{b}{cm^2\ sec}$$

$$\int \sigma^{boron}(E)\ \phi(E)\ dE = 1.776 \times 10^{16} \frac{b}{cm^2\ sec}$$

$$\int \sigma_f^{fuel}(E)\ \phi(E)\ dE = 1.456 \times 10^{16} \frac{b}{cm^2\ sec}$$

$$\sigma_f^{fuel}(2200\ m/s) = 550\ b; \qquad \bar{\sigma}^{fuel} = 78.2\ b$$

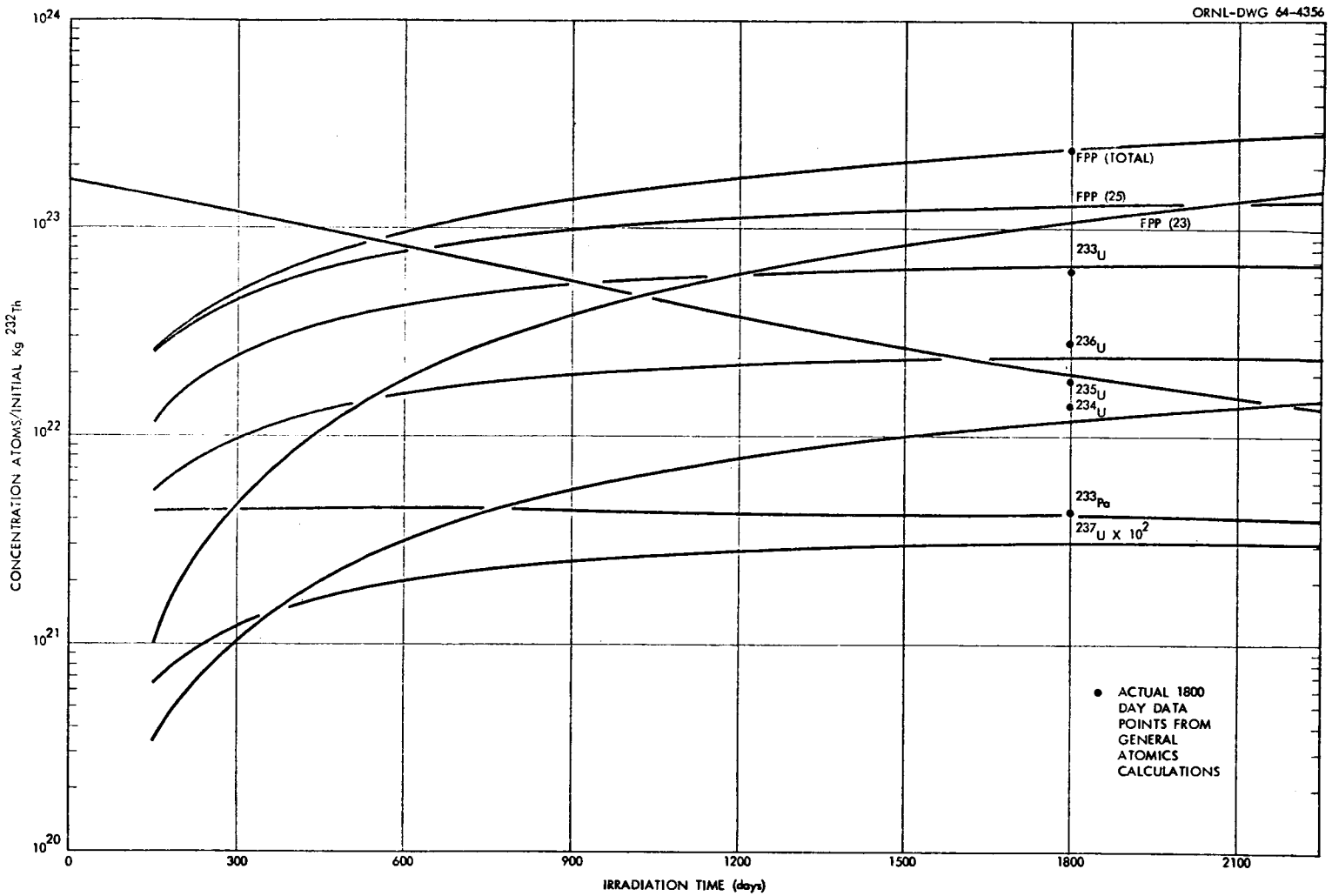

Fig. 1. Effect of Irradiation Time on Isotopic Concentrations in ESADA Reactor.

Table 1. Fission Product Concentrations Due to ^{235}U Fissions

Isotope	Concentration of Fission Product (atoms/original kilogram ^{232}Th) After an Irradiation Time (days)															
	150	300	450	600	750	900	1050	1200	1350	1500	1650	1800	1950	2100	2250	2400
^{95}Zr	7.676+20	7.817+20	6.74 +20	5.623+20	4.661+20	3.861+20	3.204+20	2.665+20	2.225+20	1.866+20	1.574+20	1.336+20	1.144+20	9.896+19	8.653+19	7.659+19
^{95}Nb	3.432+20	4.361+20	3.94 +20	3.322+20	2.759+20	2.286+20	1.896+20	1.576+20	1.314+20	1.1 +20	9.255+19	7.84 +19	6.693+19	5.768+19	5.023+19	4.427+19
^{ST}Zr	7.87 +21	1.436+22	1.972+22	2.415+22	2.781+22	3.084+22	3.335+22	3.543+22	3.717+22	3.863+22	3.986+22	4.09 +22	4.18 +22	4.257+22	4.324+22	4.383+22
^{88}Sr	9.302+20	1.698+21	2.332+21	2.856+21	3.289+21	3.648+21	3.946+21	4.194+21	4.4 +21	4.574+21	4.721+21	4.845+21	4.952+21	5.045+21	5.126+21	5.198+21
^{89}Sr	5.129+20	4.959+20	4.198+20	3.483+20	2.882+20	2.387+20	1.981+20	1.649+20	1.377+20	1.155+20	9.749+19	8.286+19	7.103+19	6.149+19	5.383+19	4.771+19
^{90}Sr	1.47 +21	2.668+21	3.642+21	4.432+21	5.07 +21	5.585+21	5.998+21	6.327+21	6.588+21	6.793+21	6.954+21	7.079+21	7.174+21	7.245+21	7.298+21	7.336+21
^{ST}Mo	6.269+21	1.144+22	1.571+22	1.923+22	2.213+22	2.454+22	2.653+22	2.819+22	2.956+22	3.072+22	3.169+22	3.251+22	3.321+22	3.381+22	3.434+22	3.48 +22
^{85}Kr	7.43 +19	1.333+20	1.797+20	2.159+20	2.437+20	2.646+20	2.8 +20	2.909+20	2.983+20	3.027+20	3.049+20	3.051+20	3.04 +20	3.018+20	2.987+20	2.95 +20
^{ST}Kr	9.963+20	1.819+21	2.5 +21	3.059+21	3.523+21	3.907+21	4.226+21	4.491+21	4.713+21	4.899+21	5.056+21	5.189+21	5.303+21	5.402+21	5.489+21	5.566+21
^{103}Ru	2.541+20	2.298+20	1.913+20	1.582+20	1.309+20	1.084+20	8.998+19	7.491+19	6.259+19	5.255+19	4.439+19	3.776+19	3.241+19	2.809+19	2.463+19	2.187+19
^{106}Ru	8.261+19	1.303+20	1.543+20	1.625+20	1.607+20	1.527+20	1.413+20	1.282+20	1.148+20	1.018+20	8.954+19	7.84 +19	6.845+19	5.97 +19	5.209+19	4.556+19
^{ST}Ru	2.757+21	5.032+21	6.909+21	8.46 +21	9.741+21	1.08 +22	1.168+22	1.241+22	1.302+22	1.353+22	1.396+22	1.432+22	1.463+22	1.49 +22	1.514+22	1.535+22
^{133}Xe	7.575+19	6.254+19	5.165+19	4.269+19	3.533+19	2.928+19	2.433+19	2.028+19	1.7 +19	1.428+19	1.209+19	1.031+19	8.881+18	7.729+18	6.806+18	6.07 +18
^{ST}Xe	4.538+21	8.283+21	1.138+22	1.393+22	1.604+22	1.779+22	1.924+22	2.045+22	2.146+22	2.231+22	2.302+22	2.363+22	2.415+22	2.46 +22	2.5 +22	2.534+22
^{131}I	5.116+19	4.223+19	3.488+19	2.883+19	2.385+19	1.977+19	1.643+19	1.369+19	1.146+19	9.635+18	8.156+18	6.958+18	5.99 +18	5.211+18	4.588+18	4.09 +18
^{ST}I	3.13 +20	5.703+20	7.818+20	9.556+20	1.098+21	1.215+21	1.312+21	1.391+21	1.456+21	1.51 +21	1.554+21	1.591+21	1.622+21	1.647+21	1.67 +21	1.688+21
^{127}Te	8.208+18	9.393+18	8.59 +18	7.362+18	6.171+18	5.135+18	4.266+18	3.549+18	2.96 +18	2.479+18	2.087+18	1.769+18	1.511+18	1.302+18	1.135+18	1.0 +18
^{129}Te	2.472+19	2.146+19	1.777+19	1.469+19	1.215+19	1.006+19	8.356+18	6.958+18	5.816+18	4.885+18	4.128+18	3.514+18	3.018+18	2.619+18	2.298+18	2.042+18
^{ST}Te	6.563+20	1.198+21	1.645+21	2.015+21	2.321+21	2.574+21	2.784+21	2.959+21	3.105+21	3.227+21	3.33 +21	3.418+21	3.494+21	3.559+21	3.616+21	3.667+21
^{137}Cs	1.469+21	2.666+21	3.637+21	4.424+21	5.058+21	5.568+21	5.976+21	6.3 +21	6.556+21	6.757+21	6.912+21	7.032+21	7.121+21	7.187+21	7.235+21	7.267+21
^{ST}Cs	3.175+21	5.782+21	7.921+21	9.674+21	1.111+22	1.229+22	1.325+22	1.403+22	1.468+22	1.521+22	1.564+22	1.6 +22	1.629+22	1.653+22	1.674+22	1.691+22
^{140}Ba	1.808+20	1.493+20	1.233+20	1.019+20	8.432+19	6.988+19	5.805+19	4.837+19	4.047+19	3.403+19	2.88 +19	2.456+19	2.113+19	1.837+19	1.616+19	1.44 +19
^{140}La	2.374+19	1.96 +19	1.619+19	1.338+19	1.107+19	9.175+18	7.621+18	6.35 +18	5.312+18	4.466+18	3.779+18	3.222+18	2.772+18	2.41 +18	2.12 +18	1.889+18
^{ST}Ba	1.572+21	2.87 +21	3.94 +21	4.825+21	5.557+21	6.162+21	6.664+21	7.082+21	7.43 +21	7.722+21	7.968+21	8.177+21	8.356+21	8.511+21	8.646+21	8.766+21
^{139}La	1.504+21	2.742+21	3.76 +21	4.597+21	5.286+21	5.852+21	6.318+21	6.702+21	7.019+21	7.282+21	7.499+21	7.681+21	7.834+21	7.963+21	8.073+21	8.168+21
^{141}Ce	4.255+20	3.677+20	3.043+20	2.515+20	2.08 +20	1.723+20	1.431+20	1.191+20	9.959+19	8.366+19	7.07 +19	6.02 +19	5.17 +19	4.486+19	3.938+19	3.5 +19
^{143}Pr	1.906+20	1.574+20	1.3 +20	1.075+20	8.891+19	7.368+19	6.121+19	5.1 +19	4.266+19	3.587+19	3.036+19	2.588+19	2.227+19	1.936+19	1.703+19	1.518+19
^{144}Ce	1.279+21	1.95 +21	2.235+21	2.283+21	2.192+21	2.026+21	1.827+21	1.618+21	1.416+21	1.229+21	1.061+21	9.136+20	7.959+20	6.77 +20	5.85 +20	5.081+20
^{147}Pm	6.106+20	1.042+21	1.333+21	1.517+21	1.62 +21	1.662+21	1.659+21	1.623+21	1.564+21	1.491+21	1.409+21	1.322+21	1.234+21	1.147+21	1.063+21	9.833+20
TFE	1.142+22	2.084+22	2.862+22	3.505+22	4.037+22	4.477+22	4.842+22	5.147+22	5.4 +22	5.613+22	5.793+22	5.946+22	6.077+22	6.19 +22	6.29 +22	6.378+22

Table 2. Fission Product Concentrations Due to ^{233}U Fissions

Isotope	Concentration of Fission Product (atoms/original kilogram ^{232}Th) After an Irradiation Time (days)															
	150	300	450	600	750	900	1050	1200	1350	1500	1650	1800	1950	2100	2250	2400
^{95}Zr	4.224+19	1.358+20	2.25 +20	2.984+20	3.567+20	4.025+20	4.383+20	4.66 +20	4.874+20	5.036+20	5.158+20	5.248+20	5.312+20	5.355+20	5.382+20	5.396+20
^{95}Nb	1.246+19	5.782+19	1.086+20	1.523+20	1.873+20	2.15 +20	2.366+20	2.535+20	2.665+20	2.764+20	2.839+20	2.895+20	2.935+20	2.962+20	2.98 +20	2.99 +20
^{ST}Zr	3.294+20	1.551+21	3.538+21	6.13 +21	9.198+21	1.264+22	1.637+22	2.032+22	2.445+22	2.87 +22	3.306+22	3.748+22	4.196+22	4.646+22	5.1 +22	5.552+22
^{88}Sr	4.947+19	2.329+20	5.314+20	9.208+20	1.382+21	1.899+21	2.459+21	3.054+21	3.674+21	4.315+21	4.97 +21	5.635+21	6.309+21	6.988+21	7.67 +21	8.353+21
^{89}Sr	3.945+19	1.214+20	1.963+20	2.569+20	3.048+20	3.423+20	3.716+20	3.943+20	4.117+20	4.25 +20	4.349+20	4.422+20	4.473+20	4.508+20	4.53 +20	4.54 +20
^{90}Sr	6.412+19	3.001+20	6.839+20	1.18 +21	1.764+21	2.415+21	3.115+21	3.851+21	4.614+21	5.394+21	6.185+21	6.982+21	7.78 +21	8.577+21	9.369+21	1.016+22
^{ST}Mo	2.185+20	1.029+20	2.347+20	4.065+21	6.099+21	8.379+21	1.085+22	1.347+22	1.62 +22	1.902+22	2.19 +22	2.483+22	2.779+22	3.077+22	3.377+22	3.677+22
^{85}Kr	1.177+18	5.482+18	1.237+19	2.118+19	3.14 +19	4.262+19	5.452+19	6.684+19	7.938+19	9.2 +19	1.046+20	1.17 +20	1.292+20	1.411+20	1.520+20	1.641+20
^{ST}Kr	5.511+19	3.147+20	7.363+20	1.307+21	2.006+21	2.815+21	3.72 +21	4.706+21	5.762+21	6.88 +21	8.044+21	9.253+21	1.05 +22	1.177+22	1.307+22	1.439+22
^{103}Ru	3.155+18	2.637+19	4.13 +19	5.318+19	6.254+19	6.986+19	7.557+19	8.0 +19	8.339+19	8.6 +19	8.789+19	8.929+19	9.028+19	9.094+19	9.134+19	9.154+19
^{106}Ru	2.554+18	1.1 +19	2.293+19	3.629+19	4.981+19	6.268+19	7.447+19	8.5 +19	9.414+19	1.02 +20	1.086+20	1.141+20	1.186+20	1.222+20	1.251+20	1.274+20
^{ST}Ru	7.124+19	3.354+20	7.652+20	1.326+21	1.989+21	2.733+21	3.539+21	4.394+21	5.286+21	6.206+21	7.148+21	8.104+21	9.071+21	1.004+22	1.102+22	1.2 +22
^{133}Xe	7.239+18	1.579+19	2.261+19	2.798+19	3.22 +19	3.55 +19	3.807+19	4.005+19	4.156+19	4.271+19	4.356+19	4.417+19	4.459+19	4.487+19	4.503+19	4.509+19
^{ST}Xe	2.137+20	1.006+21	2.296+21	3.979+21	5.97 +21	8.204+21	1.063+22	1.319+22	1.588+22	1.864+22	2.147+22	2.435+22	2.726+22	3.019+22	3.313+22	3.609+22
^{131}I	6.325+18	1.41 +19	2.03 +19	2.518+19	2.902+19	3.202+19	3.436+19	3.616+19	3.754+19	3.858+19	3.935+19	3.991+19	4.03 +19	4.055+19	4.07 +19	4.076+19
^{ST}I	1.236+19	5.813+19	1.325+20	2.293+20	3.436+20	4.716+20	6.1 +20	7.565+20	9.089+20	1.066+21	1.226+21	1.388+21	1.552+21	1.716+21	1.881+21	2.045+21
^{127}Te	4.09 +17	1.434+18	2.511+18	3.448+18	4.213+18	4.822+18	5.3 +18	5.674+18	5.962+18	6.182+18	6.348+18	6.471+18	6.56 +18	6.621+18	6.661+18	6.683+18
^{129}Te	1.625+18	4.442+18	6.808+18	8.682+18	1.015+19	1.131+19	1.221+19	1.29 +19	1.343+19	1.384+19	1.414+19	1.436+19	1.451+19	1.462+19	1.468+19	1.471+19
^{ST}Te	2.666+19	1.256+20	2.864+20	4.963+20	7.448+20	1.023+21	1.326+21	1.646+21	1.98 +21	2.326+21	2.679+21	3.038+21	3.4 +21	3.766+21	4.134+21	4.502+21
^{137}Cs	6.898+19	3.236+20	7.354+20	1.269+21	1.896+21	2.594+21	3.345+21	4.134+21	4.951+21	5.787+21	6.633+21	7.485+21	8.337+21	9.188+21	1.003+22	1.087+22
^{ST}Cs	1.128+20	5.217+20	1.17 +21	1.994+21	2.947+21	3.993+21	5.105+21	6.263+21	7.453+21	8.661+21	9.882+21	1.111+22	1.233+22	1.355+22	1.477+22	1.598+22
^{140}Ba	1.694+19	3.928+19	5.713+19	7.118+19	8.219+19	9.078+19	9.746+19	1.026+20	1.065+20	1.095+20	1.117+20	1.133+20	1.144+20	1.151+20	1.155+20	1.156+20
^{140}La	2.166+18	5.099+18	7.445+18	9.29 +18	1.074+19	1.187+19	1.274+19	1.342+19	1.394+19	1.433+19	1.461+19	1.482+19	1.497+19	1.506+19	1.511+19	1.513+19
^{ST}Ba	6.993+19	3.293+20	7.512+20	1.302+21	1.953+21	2.683+21	3.475+21	4.315+21	5.192+21	6.1 +21	7.021+21	7.961+21	8.911+21	9.869+21	1.083+22	1.179+22
^{139}La	5.94 +19	2.795+20	6.37 +20	1.103+21	1.653+21	2.269+21	2.936+21	3.642+21	4.377+21	5.134+21	5.907+21	6.69 +21	7.481+21	8.276+21	9.073+21	9.869+21
^{141}Ce	2.829+19	7.676+19	1.173+20	1.494+20	1.746+20	1.944+20	2.098+20	2.217+20	2.308+20	2.377+20	2.429+20	2.466+20	2.493+20	2.51 +20	2.521+20	2.526+20
^{143}Pr	1.374+19	3.214+19	4.689+19	5.851+19	6.764+19	7.479+19	8.034+19	8.464+19	8.792+19	9.041+19	9.225+19	9.359+19	9.452+19	9.513+19	9.548+19	9.563+19
^{144}Ce	3.584+19	1.513+20	3.088+20	4.799+20	6.473+20	8.018+20	9.391+20	1.058+21	1.158+21	1.241+21	1.31 +21	1.365+21	1.408+21	1.442+21	1.468+21	1.487+21
^{147}Pm	1.714+19	7.745+19	1.693+20	2.807+20	4.028+20	5.292+20	6.552+20	7.775+20	8.939+20	1.003+21	1.104+21	1.197+21	1.281+21	1.357+21	1.424+21	1.485+21
TRE	3.672+20	1.729+21	3.944+21	6.835+21	1.026+22	1.409+22	1.825+22	2.267+22	2.727+22	3.202+22	3.689+22	4.183+22	4.683+22	5.186+22	5.692+22	6.199+22

Table 3. Total Fission Product Concentrations

Isotope	Concentration of Fission Product (atoms/original kilogram ^{232}Th) After an Irradiation Time (days)															
	150	300	450	600	750	900	1050	1200	1350	1500	1650	1800	1950	2100	2250	2400
^{95}Zr	8.098+20	9.175+20	8.99 +20	8.607+20	8.228+20	7.886+20	7.587+20	7.325+20	7.099+20	6.902+20	6.732+20	6.584+20	6.456+20	6.345+20	6.247+20	6.162+20
^{95}Nb	3.557+20	4.939+20	5.026+20	4.845+20	4.632+20	4.436+20	4.262+20	4.111+20	3.979+20	3.864+20	3.765+20	3.679+20	3.604+20	3.539+20	3.482+20	3.433+20
^{ST}Zr	8.2 +21	1.591+22	2.326+22	3.028+22	3.701+22	4.346+22	4.972+22	5.575+22	6.162+22	6.733+22	7.292+22	7.838+22	8.376+22	8.903+22	9.424+22	9.935+22
^{88}Sr	9.8 +20	1.931+21	2.385+21	3.777+21	4.671+21	5.547+21	6.405+21	7.248+21	8.074+21	8.889+21	9.691+21	1.048+22	1.126+22	1.203+22	1.28 +22	1.355+22
^{89}Sr	5.524+20	6.173+20	6.161+20	6.052+20	5.93 +20	5.81 +20	5.697+20	5.592+20	5.494+20	5.405+20	5.324+20	5.251+20	5.183+20	5.123+20	5.068+20	5.017+20
^{90}Sr	1.534+21	2.968+21	4.326+21	5.612+21	6.834+21	8.0 +21	9.113+21	1.018+22	1.12 +22	1.219+22	1.314+22	1.406+22	1.495+22	1.582+22	1.667+22	1.75 +22
^{ST}Mo	5.466+21	1.247+22	1.595+22	2.33 +22	2.823+22	3.292+22	3.738+22	4.166+22	4.576+22	4.974+22	5.359+22	5.734+22	6.1 +22	6.458+22	6.811+22	7.157+22
^{85}Kr	7.546+19	1.388+20	1.921+20	2.371+20	2.751+20	3.072+20	3.345+20	3.577+20	3.777+20	3.947+20	4.095+20	4.221+20	4.332+20	4.429+20	4.515+20	4.591+20
^{ST}Kr	1.061+21	2.134+21	3.236+21	4.366+21	5.529+21	6.722+21	7.946+21	9.197+21	1.048+22	1.178+22	1.31 +22	1.444+22	1.58 +22	1.717+22	1.856+22	1.996+22
^{103}Ru	2.633+20	2.562+20	2.526+20	2.114+20	1.934+20	1.783+20	1.656+20	1.549+20	1.46 +20	1.386+20	1.323+20	1.271+20	1.227+20	1.19 +20	1.16 +20	1.134+20
^{106}Ru	8.516+19	1.413+20	1.772+20	1.988+20	2.105+20	2.154+20	2.158+20	2.132+20	2.089+20	2.038+20	1.981+20	1.925+20	1.871+20	1.819+20	1.772+20	1.73 +20
^{ST}Ru	2.828+21	5.367+21	7.674+21	9.786+21	1.173+22	1.353+22	1.522+22	1.68 +22	1.831+22	1.974+22	2.111+22	2.242+22	2.37 +22	2.494+22	2.616+22	2.735+22
^{133}Xe	6.299+19	7.633+19	7.426+19	7.067+19	6.753+19	6.478+19	6.24 +19	6.033+19	5.856+19	5.699+19	5.565+19	5.448+19	5.347+19	5.26 +19	5.184+19	5.116+19
^{ST}Xe	4.752+21	9.289+21	1.368+22	1.791+22	2.201+22	2.599+22	2.987+22	3.364+22	3.734+22	4.095+22	4.449+22	4.798+22	5.141+22	5.479+22	5.813+22	6.143+22
^{131}I	5.749+19	5.633+19	5.518+19	5.401+19	5.287+19	5.179+19	5.079+19	4.985+19	4.9 +19	4.822+19	4.751+19	4.687+19	4.629+19	4.576+19	4.529+19	4.485+19
^{ST}I	3.254+20	6.284+20	9.143+20	1.185+21	1.442+21	1.687+21	1.922+21	2.148+21	2.365+21	2.576+21	2.78 +21	2.979+21	3.174+21	3.363+21	3.551+21	3.733+21
^{127}Te	8.617+18	1.083+19	1.11 +19	1.081+19	1.038+19	9.957+18	9.566+18	9.223+18	8.922+18	8.661+18	8.435+18	8.24 +18	8.071+18	7.923+18	7.796+18	7.683+18
^{129}Te	2.635+19	2.59 +19	2.458+19	2.337+19	2.23 +19	2.137+19	2.057+19	1.986+19	1.925+19	1.873+19	1.827+19	1.787+19	1.753+19	1.724+19	1.698+19	1.675+19
^{ST}Te	6.53 +20	1.324+21	1.931+21	2.511+21	3.066+21	3.597+21	4.11 +21	4.605+21	5.085+21	5.553+21	6.009+21	6.456+21	6.894+21	7.325+21	7.75 +21	8.169+21
^{137}Cs	1.538+21	2.99 +21	4.372+21	5.693+21	6.954+21	8.162+21	9.321+21	1.043+22	1.151+22	1.254+22	1.355+22	1.452+22	1.546+22	1.638+22	1.727+22	1.814+22
^{ST}Cs	3.288+21	6.304+21	9.09 +21	1.167+22	1.406+22	1.628+22	1.836+22	2.029+22	2.213+22	2.387+22	2.552+22	2.711+22	2.862+22	3.008+22	3.151+22	3.289+22
^{140}Ba	1.977+20	1.886+20	1.804+20	1.731+20	1.665+20	1.607+20	1.555+20	1.51 +20	1.47 +20	1.435+20	1.405+20	1.379+20	1.355+20	1.335+20	1.317+20	1.3 +20
^{140}La	2.591+19	2.47 +19	2.364+19	2.267+19	2.181+19	2.105+19	2.036+19	1.977+19	1.925+19	1.88 +19	1.839+19	1.804+19	1.774+19	1.747+19	1.723+19	1.702+19
^{ST}Ba	1.642+21	3.199+21	4.691+21	6.127+21	7.51 +21	8.845+21	1.014+22	1.14 +22	1.262+22	1.382+22	1.5 +22	1.614+22	1.727+22	1.838+22	1.948+22	2.056+22
^{139}La	1.563+21	3.022+21	4.397+21	5.7 +21	6.939+21	8.121+21	9.254+21	1.034+22	1.14 +22	1.242+22	1.341+22	1.437+22	1.532+22	1.624+22	1.715+22	1.804+22
^{141}Ce	4.538+20	4.445+20	4.216+20	4.01 +20	3.826+20	3.667+20	3.529+20	3.408+20	3.304+20	3.214+20	3.136+20	3.068+20	3.01 +20	2.959+20	2.915+20	2.876+20
^{143}Pr	2.043+20	1.895+20	1.769+20	1.66 +20	1.566+20	1.485+20	1.416+20	1.346+20	1.306+20	1.263+20	1.226+20	1.195+20	1.168+20	1.145+20	1.125+20	1.108+20
^{144}Ce	1.315+21	2.1 +21	2.544+21	2.763+21	2.839+21	2.828+21	2.766+21	2.676+21	2.574+21	2.47 +21	2.371+21	2.279+21	2.194+21	2.119+21	2.053+21	1.995+21
^{147}Pm	6.277+20	1.12 +21	1.502+21	1.8 +21	2.023+21	2.191+21	2.314+21	2.401+21	2.458+21	2.494+21	2.513+21	2.519+21	2.515+21	2.504+21	2.487+21	2.468+21
TRE	1.179+22	2.257+22	3.256+22	4.189+22	5.063+22	5.886+22	6.667 22	7.414+22	8.127+22	8.815+22	9.482+22	1.013+23	1.076+23	1.138+23	1.198+23	1.258+23

σ^{boron} (2200 m/s) = 755 b; $\bar{\sigma}^{boron}$ = 95.4 b

$\phi_{fast}/\phi_{thermal}$ = 2.09

In our calculations using the ISOCRUNCH code, it was necessary to use a modified one group cross-section. We used a Westcott type correlation which calculates an effective 2200 m/sec cross-section from the thermal and resonance values and uses an effective 2200 m/sec flux to obtain the true reaction rate. In general the relationship between the Westcott notation and the values given by GA is as follows:

$$\hat{\sigma}\phi(2200\ m/s) = \int \sigma(E)\ \phi\ (E)\ dE\ .$$

In our analysis using the ISOCRUNCH code, the following values were used:

ϕ(2200 m/s)	=	2.288×10^{13} n/cm^2 sec
$\hat{\sigma}(02)$	=	22.05 b
$\hat{\sigma}(13)$	=	228 b
$\hat{\sigma}_f(23)$	=	679 b
$\hat{\sigma}_c(23)$	=	83 b
$\hat{\sigma}(24)$	=	254 b
$\hat{\sigma}_f(25)$	=	531 b
$\hat{\sigma}_c(25)$	=	116 b
$\hat{\sigma}_c(26)$	=	92 b

In many cases the ratios between cross-sections in the above list may not be the same as the corresponding ratios in Jaye's list. However, it was necessary to adjust several cross-sections in order to get a reasonable fit to the data at 1800 days using our constant cross-section, constant flux analyses.

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