

## Fission Products Per Tonne of Fuel

used for 50.68 GW-day LWR burnup at power of 36.5 MW and  $3.14 \times 10^{14} N/cm^2/s$  neutron flux,  
 after fifty years' storage, as calculated by ORIGEN2 version 2.1 on 9 October 2013.  
 Radiotoxicity in Sieverts computed for adult ingestion using dose factors from ICRP publication 119

Isotope ‡	Mass grams	Moles	Radioactivity			Half Life	Energy per Bq-s	Thermal Power		Radiotoxicity	
			GBq	GBq/gm	†			Watts	Watts/gm	Sv	Sv/gm
<sup>86</sup> Sr	923.6 mg	10.75 mM									
<sup>87</sup> Sr	7.616 mg	87.63 μM									
<sup>88</sup> Sr	519.2 gm	5.906 M									
<sup>90</sup> Sr	237.4 gm	2.640 M	1.199×10 <sup>6</sup>	5.051 TBq	β	28.79 y	195.8 keV	37.61 W	158.4 mW	33.57 MSv	141.4 kSv
E <sub>38</sub> Sr	757.5 gm	8.558 M	1.199×10 <sup>6</sup>	1.583 TBq				37.61 W	49.65 mW	33.57 MSv	44.32 kSv
<sup>133</sup> Cs	1.616 kg	12.16 M									
<sup>134</sup> Cs	11.77 μg	87.90 nM	563.9 MBq	47.91 TBq	ε	2.065 y	1.717 MeV	155.1 μW	13.18 W	10.71 Sv	910.3 kSv
<sup>135</sup> Cs	619.6 gm	4.593 M	26.41 GBq	42.62 MBq	β	2.300 My	56.30 keV	238.2 μW	384.4 nW	52.82 Sv	85.25 mSv
<sup>137</sup> Cs	570.0 gm	4.163 M	1.835×10 <sup>6</sup>	3.219 TBq	β	30.04 y	186.6 keV	54.86 W	96.25 mW	23.85 MSv	41.85 kSv
E <sub>55</sub> Cs	2.806 kg	20.92 M	1.835×10 <sup>6</sup>	654.1 GBq				54.86 W	19.55 mW	23.86 MSv	8.503 kSv
<sup>89</sup> Y	676.0 gm	7.604 M									
<sup>90</sup> Y	59.54 mg	662.2 μM	1.199×10 <sup>6</sup>	2.014×10 <sup>7</sup>	β	2.671 d	935.0 keV	179.6 W	3.016 kW	3.237 MSv	54.37 MSv
E <sub>39</sub> Y	676.1 gm	7.604 M	1.199×10 <sup>6</sup>	1.774 TBq				179.6 W	265.7 mW	3.237 MSv	4.788 kSv
<sup>150</sup> Eu	173.6 ng	1.158 nM	425.5 kBq	2.451 TBq	ε	36.36 y	1.540 MeV	105.0 nW	604.8 mW	553.2 μSv	3.186 kSv
<sup>151</sup> Eu	7.313 gm	48.88 mM	380.3 μBq	52.00 μBq	α	≥ 10 <sup>18</sup> y	1.905 MeV	≤ 1 pW	≤ 1 pW		
<sup>152</sup> Eu	4.929 mg	32.44 μM	31.55 GBq	6.401 TBq	ε	13.52 y	1.276 MeV	6.449 mW	1.308 W	44.17 Sv	8.961 kSv
<sup>153</sup> Eu	195.8 gm	1.280 M									
<sup>154</sup> Eu	1.172 gm	7.614 mM	11.71 TBq	9.991 TBq	β	8.593 y	1.509 MeV	2.831 W	2.416 W	23.42 kSv	19.98 kSv
<sup>155</sup> Eu	23.82 mg	153.8 μM	410.0 GBq	17.21 TBq	β	4.753 y	122.7 keV	8.061 mW	338.4 mW	131.2 Sv	5.508 kSv
E <sub>63</sub> Eu	204.3 gm	1.337 M	12.15 TBq	59.47 GBq				2.846 W	13.93 mW	23.60 kSv	115.5 Sv
<sup>108</sup> Cd	694.2 μg	6.434 μM	207.6 nBq	299.0 μBq	ε	410.0 Py	272.0 keV	≤ 1 pW	≤ 1 pW		
<sup>109</sup> Cd	≤ 1 pg	≤ 1 pM	144.8 μBq	95.58 TBq	ε	1.267 y	19.60 keV	≤ 1 pW	300.1 mW	≤ 1 pSv	191.2 kSv
<sup>110</sup> Cd	77.24 gm	702.8 mM									
<sup>111</sup> Cd	45.72 gm	412.3 mM									
<sup>112</sup> Cd	26.97 gm	241.0 mM									
<sup>113</sup> Cd	212.4 mg	1.881 mM	3.232 mBq	15.22 mBq	β	7.700 Py	93.30 keV	≤ 1 pW	≤ 1 pW	80.79 pSv	380.4 pSv
<sup>113m</sup> Cd	41.28 mg	365.6 μM	331.4 GBq	8.028 TBq	γ	14.10 y	284.0 keV	15.08 mW	365.3 mW	7.622 kSv	184.6 kSv
<sup>114</sup> Cd	34.99 gm	307.2 mM	6.772 mBq	193.5 μBq	2β	600.0 Py	536.0 keV	≤ 1 pW	≤ 1 pW		
<sup>116</sup> Cd	12.55 gm	108.3 mM	42.12 μBq	3.357 μBq	2β	≥ 10 <sup>18</sup> y	2.804 MeV	≤ 1 pW	≤ 1 pW		
A <sub>48</sub> Cd	197.7 gm	1.774 M	331.4 GBq	1.676 GBq				15.08 mW	76.27 μW	7.622 kSv	38.55 Sv
<sup>146</sup> Sm	13.66 mg	93.62 μM	17.69 kBq	1.295 MBq	α	100.0 My	2.539 MeV	7.197 nW	526.9 nW	955.3 μSv	69.93 mSv
<sup>147</sup> Sm	243.8 gm	1.659 M	205.1 kBq	841.3 Bq	α	106.0 Gy	2.310 MeV	75.90 nW	311.3 pW	10.05 mSv	41.22 μSv

†First emission from decay with highest branching ratio; ‡Electrorefiner destination: A = anode, C = cathode, E = electrolyte, G = gas

Isotope ‡	Mass grams	Moles	Radioactivity			Half Life	Energy per Bq-s	Thermal Power		Radiotoxicity	
			GBq	GBq/gm	†			Watts	Watts/gm	Sv	Sv/gm
<sup>148</sup> Sm	309.5 gm	2.092 M	3.458 Bq	11.17 mBq	$\alpha$	7.000 Py	2.014 MeV	1.116 pW	$\leq 1$ pW		
<sup>149</sup> Sm	4.616 gm	31.00 mM	205.0 mBq	44.41 mBq	$\alpha$	2.000 Py	1.870 MeV	$\leq 1$ pW	$\leq 1$ pW		
<sup>150</sup> Sm	478.3 gm	3.190 M									
<sup>151</sup> Sm	15.53 gm	102.9 mM	15.12 TBq	973.6 GBq	$\beta$	90.00 y	19.78 keV	47.92 mW	3.086 mW	1.482 kSv	95.41 Sv
<sup>152</sup> Sm	178.3 gm	1.174 M									
<sup>154</sup> Sm	59.76 gm	388.2 mM									
E <sub>62</sub> Sm	1.290 kg	8.638 M	15.12 TBq	11.72 GBq				47.92 mW	37.15 $\mu$ W	1.482 kSv	1.149 Sv
<sup>98</sup> Tc	10.77 mg	110.0 $\mu$ M	346.4 kBq	32.16 MBq	$\beta$	4.200 My	1.532 MeV	85.02 nW	7.894 $\mu$ W	692.8 $\mu$ Sv	64.33 mSv
<sup>99</sup> Tc	1.136 kg	11.49 M	712.6 GBq	627.3 MBq	$\beta$	214.0 ky	84.61 keV	9.659 mW	8.503 $\mu$ W	456.1 Sv	401.5 mSv
A <sub>43</sub> Tc	1.136 kg	11.49 M	712.6 GBq	627.3 MBq				9.659 mW	8.503 $\mu$ W	456.1 Sv	401.5 mSv
<sup>114</sup> Sn	3.852 mg	33.82 $\mu$ M									
<sup>115</sup> Sn	490.4 mg	4.268 mM									
<sup>116</sup> Sn	12.26 gm	105.8 mM									
<sup>117</sup> Sn	12.64 gm	108.1 mM									
<sup>118</sup> Sn	12.81 gm	108.7 mM									
<sup>119</sup> Sn	12.76 gm	107.3 mM									
<sup>119m</sup> Sn	$\leq 1$ pg	$\leq 1$ pM	408.5 pBq	165.8 TBq	$\gamma$	293.0 d	87.17 keV	$\leq 1$ pW	2.315 W	$\leq 1$ pSv	56.37 kSv
<sup>120</sup> Sn	12.99 gm	108.3 mM									
<sup>121m</sup> Sn	2.746 mg	22.71 $\mu$ M	6.009 GBq	2.188 TBq	$\beta$	55.00 y	338.0 keV	325.4 $\mu$ W	118.5 mW	2.283 Sv	831.5 Sv
<sup>122</sup> Sn	14.26 gm	117.0 mM									
<sup>124</sup> Sn	19.24 gm	155.3 mM	20.54 mBq	1.068 mBq	2 $\beta$	100.0 Py	2.287 MeV	$\leq 1$ pW	$\leq 1$ pW		
<sup>126</sup> Sn	42.48 gm	337.4 mM	44.62 GBq	1.050 GBq	$\beta$	230.0 ky	210.4 keV	1.504 mW	35.40 $\mu$ W	209.7 Sv	4.937 Sv
E <sub>50</sub> Sn	139.9 gm	1.152 M	50.63 GBq	361.8 MBq				1.829 mW	13.07 $\mu$ W	212.0 Sv	1.515 Sv
<sup>127</sup> I	84.19 gm	663.4 mM									
<sup>129</sup> I	273.4 gm	2.121 M	1.786 GBq	6.533 MBq	$\beta$	16.10 My	78.04 keV	22.33 $\mu$ W	81.68 nW	196.5 Sv	718.6 mSv
E <sub>53</sub> I	357.6 gm	2.784 M	1.786 GBq	4.995 MBq				22.33 $\mu$ W	62.45 nW	196.5 Sv	549.4 mSv
<sup>90</sup> Zr	585.1 gm	6.508 M									
<sup>91</sup> Zr	876.9 gm	9.646 M									
<sup>92</sup> Zr	956.3 gm	10.41 M									
<sup>93</sup> Zr	1.073 kg	11.55 M	99.79 GBq	93.00 MBq	$\beta$	1.530 My	19.60 keV	313.3 $\mu$ W	292.0 nW	109.8 Sv	102.3 mSv
<sup>94</sup> Zr	1.125 kg	11.98 M	26.41 Bq	23.48 mBq	2 $\beta$	6.000 Py	1.144 MeV	4.839 pW	$\leq 1$ pW		
<sup>96</sup> Zr	1.211 kg	12.63 M	4.282 mBq	3.536 $\mu$ Bq	2 $\beta$	$\geq 10^{18}$ y	3.350 MeV	$\leq 1$ pW	$\leq 1$ pW		
A <sub>40</sub> Zr	5.827 kg	62.72 M	99.79 GBq	17.12 MBq				313.3 $\mu$ W	53.76 nW	109.8 Sv	18.84 mSv
G <sub>1</sub> <sup>3</sup> H	5.201 mg	1.724 mM	1.858 TBq	357.2 TBq	$\beta$	12.33 y	5.678 keV	1.690 mW	324.9 mW	78.04 Sv	15.00 kSv
<sup>76</sup> Se	12.23 mg	161.1 $\mu$ M									
<sup>77</sup> Se	1.515 gm	19.70 mM									
<sup>78</sup> Se	3.687 gm	47.32 mM									

†First emission from decay with highest branching ratio; ‡Electrorefiner destination: A = anode, C = cathode, E = electrolyte, G = gas

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			GBq	GBq/gm	†			Watts	Watts/gm	Sv	Sv/gm
<sup>79</sup> Se	8.865 gm	112.3 mM	22.86 GBq	2.579 GBq	$\beta$	377.0 ky	42.00 keV	153.8 $\mu$ W	17.35 $\mu$ W	66.29 Sv	7.478 Sv
<sup>80</sup> Se	20.17 gm	252.4 mM									
<sup>82</sup> Se	50.43 gm	615.6 mM	67.30 $\mu$ Bq	1.334 $\mu$ Bq	$2\beta$	$\geq 10^{18}$ y	2.995 MeV	$\leq 1$ pW	$\leq 1$ pW		
E <sub>34</sub> Se	84.68 gm	1.048 M	22.86 GBq	270.0 MBq				153.8 $\mu$ W	1.816 $\mu$ W	66.29 Sv	782.9 mSv
<sup>121</sup> Sb	12.21 gm	101.0 mM									
<sup>123</sup> Sb	15.25 gm	124.1 mM									
<sup>125</sup> Sb	72.39 $\mu$ g	579.6 nM	2.767 GBq	38.22 TBq	$\beta$	2.759 y	527.4 keV	233.8 $\mu$ W	3.230 W	3.044 Sv	42.05 kSv
<sup>126</sup> Sb	2.018 $\mu$ g	16.03 nM	6.246 GBq	$3.095 \times 10^6$	$\beta$	12.40 d	3.117 MeV	3.119 mW	1.546 kW	14.99 Sv	7.428 MSv
<sup>126m</sup> Sb	15.35 ng	121.9 pM	44.62 GBq	$2.907 \times 10^9$	$\gamma$	19.10 m	2.147 MeV	15.35 mW	1.000 MW	1.606 Sv	104.6 MSv
E <sub>51</sub> Sb	27.46 gm	225.1 mM	53.63 GBq	1.953 GBq				18.70 mW	681.1 $\mu$ W	19.64 Sv	715.2 mSv
<sup>93</sup> Nb	16.90 mg	181.9 $\mu$ M									
<sup>93m</sup> Nb	8.422 mg	90.65 $\mu$ M	88.10 GBq	10.46 TBq	$\gamma$	16.13 y	29.89 keV	421.9 $\mu$ W	50.09 mW	10.57 Sv	1.255 kSv
<sup>94</sup> Nb	1.180 mg	12.57 $\mu$ M	8.184 MBq	6.936 GBq	$\beta$	19.99 ky	1.719 MeV	2.254 $\mu$ W	1.910 mW	13.91 mSv	11.79 Sv
A <sub>41</sub> Nb	26.50 mg	285.1 $\mu$ M	88.11 GBq	3.325 TBq				424.2 $\mu$ W	16.00 mW	10.59 Sv	399.4 Sv
<sup>146</sup> Pm	17.21 $\mu$ g	117.9 nM	283.6 MBq	16.48 TBq	$\beta$	5.531 y	850.7 keV	38.65 $\mu$ W	2.246 W	255.2 mSv	14.83 kSv
<sup>147</sup> Pm	283.5 $\mu$ g	1.930 $\mu$ M	9.727 GBq	34.31 TBq	$\beta$	2.623 y	60.51 keV	94.29 $\mu$ W	332.6 mW	2.529 Sv	8.921 kSv
E <sub>61</sub> Pm	300.7 $\mu$ g	2.048 $\mu$ M	10.01 GBq	33.29 TBq				132.9 $\mu$ W	442.1 mW	2.784 Sv	9.259 kSv
<sup>122</sup> Te	1.243 gm	10.20 mM									
<sup>123</sup> Te	21.28 mg	173.1 $\mu$ M	229.0 mBq	10.76 Bq	$\epsilon$	92.00 Py	17.10 keV	$\leq 1$ pW	$\leq 1$ pW	1.008 nSv	47.35 nSv
<sup>124</sup> Te	963.7 mg	7.778 mM									
<sup>125</sup> Te	29.08 gm	232.8 mM									
<sup>125m</sup> Te	1.013 $\mu$ g	8.110 nM	674.9 MBq	666.2 TBq	$\gamma$	57.40 d	141.9 keV	15.34 $\mu$ W	15.14 W	587.2 mSv	579.6 kSv
<sup>126</sup> Te	1.334 gm	10.60 mM									
<sup>128</sup> Te	170.8 gm	1.335 M	8.029 nBq	47.01 pBq	$2\beta$	$\geq 10^{18}$ y	867.2 keV	$\leq 1$ pW	$\leq 1$ pW		
<sup>130</sup> Te	547.3 gm	4.213 M	70.54 nBq	128.9 pBq	$2\beta$	$\geq 10^{18}$ y	2.528 MeV	$\leq 1$ pW	$\leq 1$ pW		
E <sub>52</sub> Te	750.7 gm	5.810 M	674.9 MBq	899.0 kBq				15.34 $\mu$ W	20.43 nW	587.2 mSv	782.1 $\mu$ Sv
<sup>165</sup> Ho	285.7 mg	1.732 mM									
<sup>166m</sup> Ho	3.425 mg	20.64 $\mu$ M	227.5 MBq	66.42 GBq	$\beta$	1.200 ky	1.869 MeV	68.12 $\mu$ W	19.89 mW	455.0 mSv	132.8 Sv
E <sub>67</sub> Ho	289.1 mg	1.753 mM	227.5 MBq	786.9 MBq				68.12 $\mu$ W	235.6 $\mu$ W	455.0 mSv	1.574 Sv
<sup>104</sup> Pd	463.0 gm	4.456 M									
<sup>105</sup> Pd	609.7 gm	5.812 M									
<sup>106</sup> Pd	594.1 gm	5.610 M									
<sup>107</sup> Pd	361.2 gm	3.379 M	6.875 GBq	19.03 MBq	$\beta$	6.500 My	10.01 keV	11.02 $\mu$ W	30.51 nW	254.4 mSv	704.2 $\mu$ Sv
<sup>108</sup> Pd	248.7 gm	2.305 M									
<sup>110</sup> Pd	82.30 gm	748.8 mM	16.51 mBq	200.6 $\mu$ Bq	$2\beta$	600.0 Py	2.000 MeV	$\leq 1$ pW	$\leq 1$ pW		
A <sub>46</sub> Pd	2.359 kg	22.31 M	6.875 GBq	2.914 MBq				11.02 $\mu$ W	4.671 nW	254.4 mSv	107.8 $\mu$ Sv

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			GBq	GBq/gm	†			Watts	Watts/gm	Sv	Sv/gm
E $^{14}_6\text{C}$	39.98 $\mu\text{g}$	2.855 $\mu\text{M}$	6.597 MBq	165.0 GBq	$\beta$	5.700 ky	49.46 keV	52.27 nW	1.307 mW	3.826 mSv	95.70 Sv
$^{107}\text{Ag}$	1.980 mg	18.52 $\mu\text{M}$									
$^{108}\text{Ag}$	$\leq 1$ pg	$\leq 1$ pM	125.4 kBq	$2.719 \times 10^{10}$	$\beta$	2.400 m	628.2 keV	12.62 nW	2.736 MW		
$^{108m}\text{Ag}$	1.461 $\mu\text{g}$	13.54 nM	1.409 MBq	964.4 GBq	$\epsilon$	418.0 y	1.634 MeV	368.8 nW	252.4 mW	3.241 mSv	2.218 kSv
$^{109}\text{Ag}$	115.4 gm	1.060 M									
$^{109m}\text{Ag}$	$\leq 1$ pg	$\leq 1$ pM	144.8 $\mu\text{Bq}$	$9.679 \times 10^{10}$	$\gamma$	39.70 s	86.95 keV	$\leq 1$ pW	1.348 MW		
$^{110}\text{Ag}$	$\leq 1$ pg	$\leq 1$ pM	362.0 pBq	$1.543 \times 10^{11}$	$\epsilon$	24.56 s	1.212 MeV	$\leq 1$ pW	29.97 MW		
$^{110m}\text{Ag}$	$\leq 1$ pg	$\leq 1$ pM	27.22 nBq	175.8 TBq	$\gamma$	249.8 d	2.816 MeV	$\leq 1$ pW	79.33 W	$\leq 1$ pSv	492.4 kSv
E $_{47}\text{Ag}$	115.4 gm	1.060 M	1.534 MBq	13.30 kBq				381.4 nW	3.305 nW	3.241 mSv	28.08 $\mu\text{Sv}$
$^{85}\text{Rb}$	179.4 gm	2.113 M									
$^{87}\text{Rb}$	361.8 gm	4.163 M	1.172 MBq	3.239 kBq	$\beta$	48.10 Gy	141.0 keV	26.47 nW	73.16 pW	1.758 mSv	4.859 $\mu\text{Sv}$
E $_{37}\text{Rb}$	541.2 gm	6.276 M	1.172 MBq	2.166 kBq				26.47 nW	48.91 pW	1.758 mSv	3.248 $\mu\text{Sv}$
$^{102}\text{Rh}$	9.937 ng	97.51 pM	444.4 kBq	44.72 TBq	$\epsilon$	2.902 y	2.153 MeV	153.3 nW	15.43 W	533.3 $\mu\text{Sv}$	53.67 kSv
$^{103}\text{Rh}$	611.3 gm	5.940 M									
$^{106}\text{Rh}$	$\leq 1$ pg	$\leq 1$ pM	32.40 Bq	$1.318 \times 10^{11}$	$\beta$	30.00 s	1.618 MeV	8.400 pW	34.16 MW		
A $_{45}\text{Rh}$	611.3 gm	5.940 M	444.4 kBq	727.0 Bq				153.3 nW	250.8 pW	533.3 $\mu\text{Sv}$	872.4 nSv
$^9\text{Be}$	29.79 $\mu\text{g}$	3.306 $\mu\text{M}$									
$^{10}\text{Be}$	198.9 $\mu\text{g}$	19.86 $\mu\text{M}$	164.5 kBq	827.0 MBq	$\beta$	1.600 My	202.6 keV	5.338 nW	26.84 $\mu\text{W}$	180.9 $\mu\text{Sv}$	909.8 mSv
E $_4\text{Be}$	228.7 $\mu\text{g}$	23.17 $\mu\text{M}$	164.5 kBq	719.3 MBq				5.338 nW	23.34 $\mu\text{W}$	180.9 $\mu\text{Sv}$	791.2 mSv
$^{99}\text{Ru}$	191.8 mg	1.939 mM									
$^{100}\text{Ru}$	218.3 gm	2.185 M									
$^{101}\text{Ru}$	1.166 kg	11.56 M									
$^{102}\text{Ru}$	1.217 kg	11.94 M									
$^{104}\text{Ru}$	863.0 gm	8.306 M									
$^{106}\text{Ru}$	$\leq 1$ pg	$\leq 1$ pM	32.40 Bq	123.9 TBq	$\beta$	1.020 y	10.03 keV	$\leq 1$ pW	199.0 mW	226.8 nSv	867.0 kSv
A $_{44}\text{Ru}$	3.464 kg	33.99 M	32.40 Bq	9.352 mBq				$\leq 1$ pW	$\leq 1$ pW	226.8 nSv	65.46 pSv
$^{113}\text{In}$	430.0 mg	3.809 mM									
$^{115}\text{In}$	2.697 gm	23.47 mM	621.2 mBq	230.3 mBq	$\beta$	441.0 Ty	242.0 keV	$\leq 1$ pW	$\leq 1$ pW	19.88 nSv	7.371 nSv
E $_{49}\text{In}$	3.127 gm	27.28 mM	621.2 mBq	198.7 mBq				$\leq 1$ pW	$\leq 1$ pW	19.88 nSv	6.357 nSv
$^{138}\text{La}$	7.637 mg	55.38 $\mu\text{M}$	5.424 Bq	710.2 Bq	$\epsilon$	102.0 Gy	1.237 MeV	1.075 pW	140.8 pW	5.966 nSv	781.2 nSv
$^{139}\text{La}$	1.849 kg	13.31 M									
E $_{57}\text{La}$	1.849 kg	13.31 M	5.424 Bq	2.933 mBq				1.075 pW	$\leq 1$ pW	5.966 nSv	3.227 pSv
$^{152}\text{Gd}$	89.89 mg	591.7 $\mu\text{M}$	72.45 mBq	806.0 mBq	$\alpha$	108.0 Ty	2.199 MeV	$\leq 1$ pW	$\leq 1$ pW	2.970 nSv	33.05 nSv
$^{153}\text{Gd}$	$\leq 1$ pg	$\leq 1$ pM	16.96 pBq	130.6 TBq	$\epsilon$	240.4 d	152.4 keV	$\leq 1$ pW	3.188 W	$\leq 1$ pSv	35.25 kSv
$^{154}\text{Gd}$	70.81 gm	460.0 mM									
$^{155}\text{Gd}$	26.02 gm	168.0 mM									

†First emission from decay with highest branching ratio; ‡Electrorefiner destination: A = anode, C = cathode, E = electrolyte, G = gas

Isotope ‡	Mass grams	Moles	Radioactivity			Half Life	Energy per Bq-s	Thermal Power		Radiotoxicity	
			GBq	GBq/gm	†			Watts	Watts/gm	Sv	Sv/gm
<sup>156</sup> Gd	125.8 gm	806.8 mM									
<sup>157</sup> Gd	196.7 mg	1.253 mM									
<sup>158</sup> Gd	33.19 gm	210.2 mM									
<sup>160</sup> Gd	2.102 gm	13.14 mM	1.337 mBq	636.2 μBq	2β	130.0 Py	1.729 MeV	≤ 1 pW	≤ 1 pW		
E <sub>64</sub> Gd	258.2 gm	1.660 M	73.79 mBq	285.8 μBq				≤ 1 pW	≤ 1 pW	2.970 nSv	11.50 pSv
<sup>169</sup> Tm	95.30 μg	564.1 nM									
<sup>171</sup> Tm	≤ 1 pg	≤ 1 pM	1.057 Bq	40.30 TBq	β	1.917 y	26.16 keV	≤ 1 pW	168.9 mW	116.3 pSv	4.433 kSv
E <sub>69</sub> Tm	95.30 μg	564.1 nM	1.057 Bq	11.09 kBq				≤ 1 pW	46.48 pW	116.3 pSv	1.220 μSv
<sup>140</sup> Ce	1.896 kg	13.55 M									
<sup>142</sup> Ce	1.711 kg	12.06 M	3.190 Bq	1.864 mBq	2β	50.00 Py	1.417 MeV	≤ 1 pW	≤ 1 pW		
<sup>144</sup> Ce	≤ 1 pg	≤ 1 pM	2.199 mBq	118.1 TBq	β	285.0 d	111.9 keV	≤ 1 pW	2.117 W	11.43 pSv	614.1 kSv
E <sub>58</sub> Ce	3.607 kg	25.61 M	3.192 Bq	884.9 μBq				≤ 1 pW	≤ 1 pW	11.43 pSv	≤ 1 pSv
<sup>141</sup> Pr	1.689 kg	11.99 M									
<sup>144</sup> Pr	≤ 1 pg	≤ 1 pM	2.199 mBq	2.797×10 <sup>9</sup>	β	17.28 m	1.240 MeV	≤ 1 pW	555.5 kW	≤ 1 pSv	139.8 MSv
<sup>144m</sup> Pr	≤ 1 pg	≤ 1 pM	26.38 μBq	6.712×10 <sup>9</sup>	γ	6.900 m	57.73 keV	≤ 1 pW	62.09 kW		
E <sub>59</sub> Pr	1.689 kg	11.99 M	2.225 mBq	1.318 μBq				≤ 1 pW	≤ 1 pW	≤ 1 pSv	≤ 1 pSv
<sup>6</sup> Li	241.9 μg	40.22 μM									
<sup>7</sup> Li	15.49 μg	2.208 μM									
E <sub>3</sub> Li	257.4 μg	42.42 μM									
<sup>66</sup> Zn	53.48 ng	811.2 pM									
<sup>67</sup> Zn	2.226 ng	33.26 pM									
<sup>68</sup> Zn	2.128 mg	31.33 μM									
<sup>70</sup> Zn	7.588 mg	108.5 μM									
E <sub>30</sub> Zn	9.716 mg	139.8 μM									
<sup>69</sup> Ga	5.671 μg	82.28 nM									
<sup>71</sup> Ga	2.257 μg	31.82 nM									
E <sub>31</sub> Ga	7.928 μg	114.1 nM									
<sup>70</sup> Ge	33.14 ng	473.9 pM									
<sup>72</sup> Ge	33.04 mg	459.4 μM									
<sup>73</sup> Ge	66.60 mg	913.3 μM									
<sup>74</sup> Ge	147.3 mg	1.993 mM									
<sup>76</sup> Ge	748.2 mg	9.855 mM	82.50 nBq	110.3 nBq	2β	≥ 10 <sup>18</sup> y	2.039 MeV	≤ 1 pW	≤ 1 pW		
E <sub>32</sub> Ge	995.1 mg	13.22 mM	82.50 nBq	82.91 nBq				≤ 1 pW	≤ 1 pW		
E <sub>33</sub> As	298.2 mg	3.980 mM									
<sup>79</sup> Br	4.918 mg	62.32 μM									
<sup>81</sup> Br	31.96 gm	395.0 mM									

‡First emission from decay with highest branching ratio; †Electrorefiner destination: A = anode, C = cathode, E = electrolyte, G = gas

Isotope ‡	Mass grams	Moles	Radioactivity			Half Life	Energy per Bq-s	Thermal Power		Radiotoxicity	
			GBq	GBq/gm	†			Watts	Watts/gm	Sv	Sv/gm
E <sup>35</sup> Br	31.96 gm	395.0 mM									
<sup>80</sup> Kr	358.8 μg	4.490 μM									
<sup>81</sup> Kr	42.35 μg	523.4 nM	32.97 kBq	778.5 MBq	ε	210.0 ky	20.81 keV	109.9 pW	2.595 μW		
<sup>82</sup> Kr	2.022 gm	24.68 mM									
<sup>83</sup> Kr	57.85 gm	697.7 mM									
<sup>84</sup> Kr	172.8 gm	2.059 M									
<sup>85</sup> Kr	1.357 gm	15.98 mM	19.71 TBq	14.52 TBq	β	10.75 y	252.7 keV	797.8 mW	587.9 mW		
<sup>86</sup> Kr	282.3 gm	3.286 M									
G <sup>36</sup> Kr	516.3 gm	6.084 M	19.71 TBq	38.17 GBq				797.8 mW	1.545 mW		
<sup>95</sup> Mo	1.116 kg	11.76 M									
<sup>96</sup> Mo	80.49 gm	839.3 mM									
<sup>97</sup> Mo	1.202 kg	12.40 M									
<sup>98</sup> Mo	1.238 kg	12.64 M	1.673 kBq	1.351 Bq	2β	100.0 Ty	112.0 keV	30.01 pW	≤ 1 pW		
<sup>100</sup> Mo	1.423 kg	14.24 M	19.03 mBq	13.37 μBq	2β	≥ 10 <sup>18</sup> y	3.034 MeV	≤ 1 pW	≤ 1 pW		
A <sup>42</sup> Mo	5.059 kg	51.89 M	1.673 kBq	330.6 mBq				30.02 pW	≤ 1 pW		
<sup>128</sup> Xe	7.057 gm	55.17 mM									
<sup>129</sup> Xe	52.88 mg	410.2 μM									
<sup>130</sup> Xe	23.11 gm	177.9 mM									
<sup>131</sup> Xe	566.1 gm	4.325 M									
<sup>132</sup> Xe	1.753 kg	13.29 M									
<sup>134</sup> Xe	2.246 kg	16.77 M	20.17 Bq	8.980 mBq	2β	11.00 Py	830.0 keV	2.682 pW	≤ 1 pW		
<sup>136</sup> Xe	3.429 kg	25.23 M	1.589 mBq	463.5 nBq	2β	≥ 10 <sup>18</sup> y	2.467 MeV	≤ 1 pW	≤ 1 pW		
G <sup>54</sup> Xe	8.024 kg	59.85 M	20.17 Bq	2.514 mBq				2.683 pW	≤ 1 pW		
<sup>132</sup> Ba	3.142 mg	23.82 μM									
<sup>134</sup> Ba	342.5 gm	2.558 M									
<sup>135</sup> Ba	1.057 gm	7.835 mM									
<sup>136</sup> Ba	42.80 gm	314.9 mM									
<sup>137</sup> Ba	1.320 kg	9.642 M									
<sup>137m</sup> Ba	87.20 μg	636.9 nM	1.736×10 <sup>6</sup>	1.991×10 <sup>10</sup>	γ	2.552 m	662.3 keV	184.2 W	2.112 MW		
<sup>138</sup> Ba	1.944 kg	14.10 M									
E <sup>56</sup> Ba	3.650 kg	26.62 M	1.736×10 <sup>6</sup>	475.6 GBq				184.2 W	50.46 mW		
<sup>142</sup> Nd	51.65 gm	364.0 mM									
<sup>143</sup> Nd	1.116 kg	7.809 M									
<sup>144</sup> Nd	2.072 kg	14.40 M	83.17 Bq	40.14 mBq	α	2.290 Py	1.905 MeV	25.38 pW	≤ 1 pW		
<sup>145</sup> Nd	975.8 gm	6.734 M									
<sup>146</sup> Nd	1.091 kg	7.477 M									
<sup>148</sup> Nd	563.2 gm	3.808 M	18.65 mBq	33.12 μBq	2β	≥ 10 <sup>18</sup> y	1.929 MeV	≤ 1 pW	≤ 1 pW		

†First emission from decay with highest branching ratio; ‡Electrorefiner destination: A = anode, C = cathode, E = electrolyte, G = gas

Isotope ‡	Mass grams	Moles	Radioactivity			Half Life	Energy per Bq-s	Thermal Power		Radiotoxicity	
			GBq	GBq/gm	†			Watts	Watts/gm	Sv	Sv/gm
<sup>150</sup> Nd E <sub>60</sub> Nd	273.6 gm 6.143 kg	1.825 M 42.41 M	1.150 mBq 83.19 Bq	4.201 $\mu$ Bq 13.54 mBq	2 $\beta$	$\geq 10^{18}$ y	3.368 MeV	$\leq 1$ pW 25.39 pW	$\leq 1$ pW $\leq 1$ pW		
E <sub>65</sub> <sup>159</sup> Tb	4.337 gm	27.29 mM									
<sup>160</sup> Dy <sup>161</sup> Dy <sup>162</sup> Dy <sup>163</sup> Dy <sup>164</sup> Dy E <sub>66</sub> Dy	612.8 mg 712.4 mg 572.7 mg 537.5 mg 133.0 mg 2.568 gm	3.832 mM 4.427 mM 3.537 mM 3.299 mM 811.3 $\mu$ M 15.91 mM									
<sup>166</sup> Er <sup>167</sup> Er <sup>168</sup> Er <sup>170</sup> Er E <sub>68</sub> Er	88.64 mg 5.663 mg 11.31 mg 59.35 ng 105.6 mg	534.2 $\mu$ M 33.92 $\mu$ M 67.35 $\mu$ M 349.3 pM 635.5 $\mu$ M									
<sup>170</sup> Yb <sup>171</sup> Yb <sup>172</sup> Yb E <sub>70</sub> Yb	39.44 $\mu$ g 3.426 $\mu$ g 143.9 ng 43.01 $\mu$ g	232.1 nM 20.04 nM 836.9 pM 253.0 nM									
Total	52.18 kg	443.5 M	6.020 $\times 10^6$	115.4 GBq				460.1 W	8.818 mW	60.70 MSv	1.163 kSv
ICRP Publication 119 does not report dose factors for isotopes with half lives less than ten minutes or greater than $10^9$ years. Dose factors for gases are given as Sv/day per Bq/m <sup>3</sup> . Radiotoxicity is not computed for gases.											
†First emission from decay with highest branching ratio; ‡Electrorefiner destination: A = anode, C = cathode, E = electrolyte, G = gas											

## Actinides and Daughters Per Tonne of Fuel

used for 50.68 GW-day LWR burnup at power of 36.5 MW and  $3.14 \times 10^{14} N/cm^2/s$  neutron flux,  
after fifty years' storage, as calculated by ORIGEN2 version 2.1 on 9 October 2013.

Radiotoxicity in Sieverts computed for adult ingestion using dose factors from ICRP publication 119

Isotope ‡	Mass grams	Moles	Radioactivity			Half Life	Energy per Bq-s	Thermal Power		Radiotoxicity	
			GBq	GBq/gm	†			Watts	Watts/gm	Sv	Sv/gm
<sup>236</sup> Pu	5.542 ng	23.48 pM	109.0 kBq	19.67 TBq	$\alpha$	2.858 y	5.870 MeV	102.5 nW	18.50 W	9.483 mSv	1.711 MSv
<sup>238</sup> Pu	219.1 gm	920.4 mM	138.9 TBq	634.0 GBq	$\alpha$	87.70 y	5.590 MeV	124.4 W	567.8 mW	31.95 MSv	145.8 kSv
<sup>239</sup> Pu	6.177 kg	25.84 M	14.21 TBq	2.300 GBq	$\alpha$	24.11 ky	5.201 MeV	11.84 W	1.917 mW	3.553 MSv	575.1 Sv
<sup>240</sup> Pu	2.989 kg	12.45 M	25.21 TBq	8.434 GBq	$\alpha$	6.563 ky	5.252 MeV	21.21 W	7.096 mW	6.302 MSv	2.109 kSv
<sup>241</sup> Pu	161.6 gm	670.4 mM	616.4 TBq	3.814 TBq	$\beta$	14.33 y	5.230 keV	516.5 mW	3.196 mW	2.959 MSv	18.31 kSv
<sup>242</sup> Pu	873.8 gm	3.610 M	123.5 GBq	141.3 MBq	$\alpha$	373.5 ky	4.981 MeV	98.56 mW	112.8 $\mu$ W	29.64 kSv	33.92 Sv
<sup>243</sup> Pu	$\leq 1$ pg	$\leq 1$ pM	33.76 kBq	$9.635 \times 10^7$	$\beta$	4.956 h	194.7 keV	1.053 nW	3.005 kW	2.870 $\mu$ Sv	8.189 MSv
<sup>244</sup> Pu	31.02 mg	127.1 $\mu$ M	20.36 kBq	656.4 kBq	$\alpha$	80.00 My	4.893 MeV	15.96 nW	514.5 nW	4.886 mSv	157.5 mSv
<sup>246</sup> Pu	$\leq 1$ pg	$\leq 1$ pM	3.603 mBq	$1.811 \times 10^6$	$\beta$	10.85 d	142.0 keV	$\leq 1$ pW	41.19 W	11.89 pSv	5.975 MSv
C <sup>94</sup> Pu	10.42 kg	43.49 M	794.8 TBq	76.28 GBq				158.1 W	15.17 mW	44.79 MSv	4.298 kSv
<sup>241</sup> Am	1.601 kg	6.642 M	203.4 TBq	127.0 GBq	$\alpha$	432.8 y	5.604 MeV	182.6 W	114.1 mW	40.68 MSv	25.41 kSv
<sup>242</sup> Am	7.560 $\mu$ g	31.23 nM	226.2 GBq	$2.992 \times 10^7$	$\beta$	16.04 h	191.5 keV	6.940 mW	918.0 W	67.86 Sv	8.976 MSv
<sup>242m</sup> Am	632.0 mg	2.611 mM	227.4 GBq	359.8 GBq	$\gamma$	141.0 y	66.62 keV	2.427 mW	3.840 mW	43.21 kSv	68.36 kSv
<sup>243</sup> Am	196.1 gm	806.8 mM	1.447 TBq	7.379 GBq	$\alpha$	7.365 ky	5.422 MeV	1.257 W	6.410 mW	289.4 kSv	1.476 kSv
<sup>245</sup> Am	$\leq 1$ pg	$\leq 1$ pM	$\leq 1$ pBq	$2.288 \times 10^8$	$\beta$	2.050 h	312.9 keV	$\leq 1$ pW	11.47 kW	$\leq 1$ pSv	14.19 MSv
<sup>246</sup> Am	$\leq 1$ pg	$\leq 1$ pM	3.603 mBq	$1.132 \times 10^9$	$\beta$	39.00 m	1.362 MeV	$\leq 1$ pW	246.9 kW	$\leq 1$ pSv	65.63 MSv
C <sup>95</sup> Am	1.798 kg	7.451 M	205.3 TBq	114.2 GBq				183.9 W	102.3 mW	41.01 MSv	22.81 kSv
<sup>242</sup> Cm	1.529 mg	6.317 $\mu$ M	187.1 GBq	122.4 TBq	$\alpha$	162.9 d	6.215 MeV	186.3 mW	121.8 W	2.245 kSv	1.468 MSv
<sup>243</sup> Cm	221.4 mg	910.9 $\mu$ M	422.9 GBq	1.910 TBq	$\epsilon$	30.00 y	6.192 MeV	419.5 mW	1.895 W	63.44 kSv	286.5 kSv
<sup>244</sup> Cm	12.53 gm	51.34 mM	37.56 TBq	2.998 TBq	$\alpha$	18.00 y	5.898 MeV	35.49 W	2.832 W	4.507 MSv	359.7 kSv
<sup>245</sup> Cm	5.597 gm	22.84 mM	35.57 GBq	6.355 GBq	$\alpha$	8.500 ky	5.598 MeV	31.90 mW	5.699 mW	7.470 kSv	1.335 kSv
<sup>246</sup> Cm	712.4 mg	2.895 mM	8.099 GBq	11.37 GBq	$\alpha$	4.730 ky	5.524 MeV	7.167 mW	10.06 mW	1.701 kSv	2.387 kSv
<sup>247</sup> Cm	9.829 mg	39.78 $\mu$ M	33.76 kBq	3.435 MBq	$\alpha$	16.00 My	5.390 MeV	29.15 nW	2.966 $\mu$ W	6.414 mSv	652.6 mSv
<sup>248</sup> Cm	760.1 $\mu$ g	3.064 $\mu$ M	119.6 kBq	157.3 MBq	$\alpha$	340.0 ky	21.00 MeV	402.4 nW	529.4 $\mu$ W	92.09 mSv	121.2 Sv
<sup>250</sup> Cm	4.738 pg	$\leq 1$ pM	14.41 mBq	3.041 GBq	$\alpha$	8.000 ky	123.3 MeV	$\leq 1$ pW	60.09 mW	63.40 nSv	13.38 kSv
C <sup>96</sup> Cm	19.07 gm	78.03 mM	38.21 TBq	2.004 TBq				36.13 W	1.895 W	4.582 MSv	240.2 kSv
<sup>232</sup> U	273.7 $\mu$ g	1.180 $\mu$ M	216.9 MBq	792.5 GBq	$\alpha$	69.80 y	5.416 MeV	188.2 $\mu$ W	687.6 mW	71.58 Sv	261.5 kSv
<sup>233</sup> U	12.89 mg	55.31 $\mu$ M	4.618 MBq	358.3 MBq	$\alpha$	159.3 ky	4.905 MeV	3.629 $\mu$ W	281.5 $\mu$ W	235.5 mSv	18.27 Sv
<sup>234</sup> U	273.1 gm	1.167 M	63.16 GBq	231.3 MBq	$\alpha$	245.7 ky	4.859 MeV	49.17 mW	180.0 $\mu$ W	3.095 kSv	11.33 Sv
<sup>235</sup> U	7.425 kg	31.59 M	594.2 MBq	80.03 kBq	$\alpha$	703.8 My	4.417 MeV	420.5 $\mu$ W	56.63 nW	27.93 Sv	3.761 mSv
<sup>236</sup> U	5.538 kg	23.46 M	13.26 GBq	2.394 MBq	$\alpha$	23.70 My	4.571 MeV	9.710 mW	1.753 $\mu$ W	623.2 Sv	112.5 mSv
<sup>237</sup> U	5.005 $\mu$ g	21.11 nM	15.12 GBq	$3.021 \times 10^6$	$\beta$	6.750 d	319.2 keV	773.3 $\mu$ W	154.5 W	11.49 Sv	2.296 MSv
<sup>238</sup> U	921.7 kg	3.872 kM	11.47 GBq	12.44 kBq	$\alpha$	4.468 Gy	4.279 MeV	7.863 mW	8.531 nW	516.2 Sv	560.0 $\mu$ Sv

†First emission from decay with highest branching ratio; ‡Electrorefiner destination: A = anode, C = cathode, E = electrolyte, G = gas



Isotope ‡	Mass grams	Moles	Radioactivity			Half Life	Energy per Bq-s	Thermal Power		Radiotoxicity	
			GBq	GBq/gm	†			Watts	Watts/gm	Sv	Sv/gm
<sup>240</sup> U C <sub>92</sub> U	≤ 1 pg	≤ 1 pM	20.34 kBq	3.428×10 <sup>7</sup>	β	14.10 h	138.4 keV	450.9 pW	760.0 W	22.37 μSv	37.71 MSv
	934.9 kg	3.928 kM	103.8 GBq	111.1 kBq				68.13 mW	72.87 nW	4.345 kSv	4.648 mSv
<sup>236</sup> Np <sup>237</sup> Np <sup>238</sup> Np <sup>239</sup> Np <sup>240m</sup> Np C <sub>93</sub> Np	2.482 mg	10.51 μM	1.210 MBq	487.5 MBq	β	152.0 ky	340.4 keV	65.98 nW	26.58 μW	20.57 mSv	8.288 Sv
	737.7 gm	3.112 M	19.25 GBq	26.09 MBq	α	2.140 My	5.156 MeV	15.90 mW	21.55 μW	2.118 kSv	2.870 Sv
	118.5 ng	497.8 pM	1.137 GBq	9.595×10 <sup>6</sup>	β	2.117 d	808.1 keV	147.2 μW	1.242 kW	1.035 Sv	8.731 MSv
	168.6 μg	705.3 nM	1.447 TBq	8.582×10 <sup>6</sup>	β	2.355 d	407.9 keV	94.55 mW	560.8 W	1.158 kSv	6.866 MSv
	≤ 1 pg	≤ 1 pM	20.34 kBq	3.919×10 <sup>9</sup>	β	7.400 m	977.4 keV	3.185 nW	613.7 kW		
	737.7 gm	3.112 M	1.467 TBq	1.989 GBq				110.6 mW	149.9 μW	3.276 kSv	4.441 Sv
<sup>227</sup> Th <sup>228</sup> Th <sup>229</sup> Th <sup>230</sup> Th <sup>231</sup> Th <sup>232</sup> Th <sup>234</sup> Th C <sub>90</sub> Th	872.7 pg	3.844 pM	993.1 kBq	1.138×10 <sup>6</sup>	α	18.72 d	6.156 MeV	979.4 nW	1.122 kW	8.739 mSv	10.01 MSv
	7.343 μg	32.20 nM	222.8 MBq	30.34 TBq	α	1.913 y	5.516 MeV	196.9 μW	26.81 W	16.04 Sv	2.185 MSv
	2.438 μg	10.64 nM	19.20 kBq	7.875 GBq	α	7.340 ky	5.159 MeV	15.87 nW	6.509 mW	9.408 mSv	3.859 kSv
	32.88 mg	142.9 μM	24.57 MBq	747.3 MBq	α	75.40 ky	4.774 MeV	18.79 μW	571.5 μW	5.160 Sv	156.9 Sv
	30.19 ng	130.7 pM	594.2 MBq	1.968×10 <sup>7</sup>	β	1.063 d	94.64 keV	9.009 μW	298.4 W	202.0 mSv	6.692 MSv
	8.420 mg	36.29 μM	34.18 Bq	4.059 kBq	α	14.05 Gy	4.083 MeV	22.36 pW	2.656 nW	7.861 μSv	933.7 μSv
	13.38 μg	57.17 nM	11.47 GBq	857.2 TBq	β	24.09 d	68.41 keV	125.7 μW	9.395 W	39.00 Sv	2.915 MSv
	41.32 mg	179.3 μM	12.31 GBq	298.0 GBq				351.4 μW	8.504 mW	60.42 Sv	1.462 kSv
<sup>231</sup> Pa <sup>233</sup> Pa <sup>234</sup> Pa <sup>234m</sup> Pa C <sub>91</sub> Pa	851.6 μg	3.686 μM	1.489 MBq	1.748 GBq	α	32.76 ky	5.085 MeV	1.213 μW	1.424 mW	1.057 Sv	1.241 kSv
	25.06 μg	107.5 nM	19.25 GBq	768.2 TBq	β	27.00 d	383.0 keV	1.181 mW	47.13 W	16.75 Sv	668.3 kSv
	201.5 pg	≤ 1 pM	14.91 MBq	7.400×10 <sup>7</sup>	β	6.780 h	2.423 MeV	5.788 μW	28.72 kW	7.604 mSv	37.74 MSv
	451.2 pg	1.928 pM	11.47 GBq	2.542×10 <sup>10</sup>	β	1.170 m	833.7 keV	1.532 mW	3.395 MW		
	876.7 μg	3.794 μM	30.74 GBq	35.06 TBq				2.720 mW	3.103 W	17.81 Sv	20.32 kSv
<sup>223</sup> Ra <sup>224</sup> Ra <sup>225</sup> Ra <sup>226</sup> Ra <sup>228</sup> Ra E <sub>88</sub> Ra	531.1 pg	2.381 pM	1.007 MBq	1.896×10 <sup>6</sup>	α	11.43 d	6.006 MeV	968.9 nW	1.824 kW	100.7 mSv	189.6 MSv
	37.79 ng	168.7 pM	222.8 MBq	5.896×10 <sup>6</sup>	α	3.640 d	5.791 MeV	206.7 μW	5.470 kW	14.48 Sv	383.2 MSv
	13.23 pg	≤ 1 pM	19.20 kBq	1.451×10 <sup>6</sup>	β	14.80 d	118.3 keV	363.8 pW	27.50 W	1.901 mSv	143.7 MSv
	7.079 μg	31.32 nM	259.1 kBq	36.60 GBq	α	1.600 ky	4.871 MeV	202.2 nW	28.56 mW	72.55 mSv	10.25 kSv
	3.220 pg	≤ 1 pM	27.89 Bq	8.661 TBq	β	5.750 y	13.00 keV	≤ 1 pW	18.04 mW	19.24 μSv	5.976 MSv
	7.117 μg	31.49 nM	224.1 MBq	31.48 TBq				207.9 μW	29.21 W	14.66 Sv	2.059 MSv
<sup>206</sup> Pb <sup>207</sup> Pb <sup>208</sup> Pb <sup>209</sup> Pb <sup>210</sup> Pb <sup>211</sup> Pb <sup>212</sup> Pb <sup>214</sup> Pb A <sub>82</sub> Pb	14.27 ng	69.28 pM									
	305.8 ng	1.477 nM									
	148.8 μg	715.5 nM									
	≤ 1 pg	≤ 1 pM	19.20 kBq	1.683×10 <sup>8</sup>	β	3.253 h	194.0 keV	596.6 pW	5.229 kW	1.094 μSv	9.592 MSv
	33.91 ng	161.5 pM	95.83 kBq	2.826 TBq	β	22.16 y	39.08 keV	600.0 pW	17.69 mW	66.12 mSv	1.950 MSv
	1.102 pg	≤ 1 pM	1.007 MBq	9.138×10 <sup>8</sup>	β	36.10 m	505.4 keV	81.54 nW	73.99 kW	181.3 μSv	164.5 MSv
	4.332 ng	20.43 pM	222.8 MBq	5.143×10 <sup>7</sup>	β	10.64 h	321.1 keV	11.46 μW	2.645 kW	1.337 Sv	308.6 MSv
	≤ 1 pg	≤ 1 pM	259.0 kBq	1.214×10 <sup>9</sup>	β	26.80 m	537.9 keV	22.32 nW	104.6 kW	36.26 μSv	169.9 MSv
149.2 μg	717.2 nM	224.2 MBq	1.503 TBq				11.57 μW	77.54 mW	1.403 Sv	9.407 kSv	
<sup>225</sup> Ac	8.935 pg	≤ 1 pM	19.20 kBq	2.149×10 <sup>6</sup>	α	10.00 d	5.891 MeV	18.12 nW	2.028 kW	460.8 μSv	51.57 MSv

†First emission from decay with highest branching ratio; ‡Electrorefiner destination: A = anode, C = cathode, E = electrolyte, G = gas

Isotope ‡	Mass grams	Moles	Radioactivity			Half Life	Energy per Bq-s	Thermal Power		Radiotoxicity	
			GBq	GBq/gm	†			Watts	Watts/gm	Sv	Sv/gm
<sup>227</sup> Ac	375.9 ng	1.656 nM	1.006 MBq	2.676 TBq	$\beta$	21.77 y	81.72 keV	13.17 nW	35.04 mW	1.107 Sv	2.944 MSv
<sup>228</sup> Ac	$\leq 1$ pg	$\leq 1$ pM	27.89 Bq	$8.298 \times 10^7$	$\beta$	6.150 h	1.458 MeV	6.514 pW	19.38 kW	11.99 nSv	35.68 MSv
E <sub>89</sub> Ac	375.9 ng	1.656 nM	1.025 MBq	2.727 TBq				31.30 nW	83.26 mW	1.107 Sv	2.945 MSv
<sup>249</sup> Cf	9.690 $\mu$ g	38.90 nM	1.469 MBq	151.6 GBq	$\alpha$	351.0 y	7.810 MeV	1.838 $\mu$ W	189.7 mW	514.2 mSv	53.06 kSv
<sup>250</sup> Cf	144.8 ng	579.0 pM	586.1 kBq	4.048 TBq	$\alpha$	13.08 y	6.265 MeV	588.3 nW	4.063 W	93.78 mSv	647.6 kSv
<sup>251</sup> Cf	946.9 ng	3.771 nM	55.57 kBq	58.69 GBq	$\alpha$	898.0 y	6.029 MeV	53.67 nW	56.68 mW	20.01 mSv	21.13 kSv
<sup>252</sup> Cf	1.303 pg	$\leq 1$ pM	25.94 Bq	19.91 TBq	$\alpha$	2.645 y	12.04 MeV	50.04 pW	38.40 W	2.335 $\mu$ Sv	1.792 MSv
C <sub>98</sub> Cf	10.78 $\mu$ g	43.25 nM	2.111 MBq	195.8 GBq				2.480 $\mu$ W	230.0 mW	627.9 mSv	58.24 kSv
<sup>210</sup> Po	576.4 pg	2.745 pM	95.83 kBq	166.3 TBq	$\alpha$	138.4 d	5.408 MeV	83.03 nW	144.0 W	115.0 mSv	199.5 MSv
<sup>211</sup> Po	$\leq 1$ pg	$\leq 1$ pM	2.819 kBq	$3.534 \times 10^{12}$	$\alpha$	516.0 ms	7.593 MeV	3.429 nW	4.299 GW		
<sup>215</sup> Po	$\leq 1$ pg	$\leq 1$ pM	1.007 MBq	$1.091 \times 10^{15}$	$\beta$	1.780 ms	7.531 MeV	1.215 $\mu$ W	$1.317 \times 10^{12}$		
<sup>216</sup> Po	$\leq 1$ pg	$\leq 1$ pM	222.8 MBq	$1.289 \times 10^{13}$	$\alpha$	150.0 ms	6.906 MeV	246.5 $\mu$ W	14.26 GW		
<sup>218</sup> Po	$\leq 1$ pg	$\leq 1$ pM	259.1 kBq	$1.047 \times 10^{10}$	$\beta$	3.098 m	6.112 MeV	253.7 nW	10.25 MW		
A <sub>84</sub> Po	576.4 pg	2.745 pM	224.2 MBq	$3.889 \times 10^8$				248.1 $\mu$ W	430.3 kW	115.0 mSv	199.5 MSv
<sup>208</sup> Bi	$\leq 1$ pg	$\leq 1$ pM	119.3 nBq	172.9 MBq	$\epsilon$	368.0 ky	2.653 MeV	$\leq 1$ pW	73.50 $\mu$ W		
<sup>209</sup> Bi	6.495 ng	31.08 pM	$\leq 1$ pBq	3.331 $\mu$ Bq	$\alpha$	$\geq 10^{18}$ y	3.137 MeV	$\leq 1$ pW	$\leq 1$ pW		
<sup>210</sup> Bi	20.87 pg	$\leq 1$ pM	95.83 kBq	$4.592 \times 10^6$	$\beta$	5.012 d	389.1 keV	5.973 nW	286.2 W	124.6 $\mu$ Sv	5.969 MSv
<sup>210m</sup> Bi	$\leq 1$ pg	$\leq 1$ pM	90.32 nBq	21.00 MBq	$\alpha$	3.000 My	5.295 MeV	$\leq 1$ pW	17.82 $\mu$ W	$\leq 1$ pSv	315.1 mSv
<sup>211</sup> Bi	$\leq 1$ pg	$\leq 1$ pM	1.007 MBq	$1.549 \times 10^{10}$	$\beta$	2.170 m	6.725 MeV	1.085 $\mu$ W	16.69 MW		
<sup>212</sup> Bi	410.9 pg	1.938 pM	222.8 MBq	$5.422 \times 10^8$	$\beta$	1.009 h	2.869 MeV	102.4 $\mu$ W	249.2 kW	57.93 mSv	141.0 MSv
<sup>213</sup> Bi	$\leq 1$ pg	$\leq 1$ pM	19.20 kBq	$7.159 \times 10^8$	$\beta$	45.59 m	709.1 keV	2.181 nW	81.32 kW	3.840 $\mu$ Sv	143.2 MSv
<sup>214</sup> Bi	$\leq 1$ pg	$\leq 1$ pM	259.0 kBq	$1.634 \times 10^9$	$\beta$	19.90 m	2.162 MeV	89.71 nW	566.0 kW	28.49 $\mu$ Sv	179.7 MSv
A <sub>83</sub> Bi	6.927 ng	33.12 pM	224.2 MBq	$3.236 \times 10^7$				103.6 $\mu$ W	14.95 kW	58.08 mSv	8.385 MSv
<sup>221</sup> Fr	$\leq 1$ pg	$\leq 1$ pM	19.20 kBq	$6.564 \times 10^9$	$\alpha$	4.900 m	6.509 MeV	20.02 nW	6.844 MW		
<sup>223</sup> Fr	$\leq 1$ pg	$\leq 1$ pM	13.89 kBq	$1.432 \times 10^9$	$\beta$	21.80 m	438.0 keV	974.7 pW	100.5 kW	33.34 $\mu$ Sv	3.437 GSv
C <sub>87</sub> Fr	$\leq 1$ pg	$\leq 1$ pM	33.09 kBq	$2.621 \times 10^9$				20.99 nW	1.663 MW	33.34 $\mu$ Sv	2.640 GSv
<sup>249</sup> Bk	$\leq 1$ pg	$\leq 1$ pM	3.680 nBq	60.66 TBq	$\beta$	320.0 d	125.0 keV	$\leq 1$ pW	1.215 W	$\leq 1$ pSv	58.84 kSv
<sup>250</sup> Bk	$\leq 1$ pg	$\leq 1$ pM	2.018 mBq	$1.440 \times 10^8$	$\beta$	3.217 h	1.172 MeV	$\leq 1$ pW	27.04 kW	$\leq 1$ pSv	20.17 MSv
C <sub>97</sub> Bk	$\leq 1$ pg	$\leq 1$ pM	2.018 mBq	$1.434 \times 10^8$				$\leq 1$ pW	26.92 kW	$\leq 1$ pSv	20.08 MSv
C <sub>99</sub> <sup>254</sup> Es	$\leq 1$ pg	$\leq 1$ pM	$\leq 1$ pBq	69.02 TBq	$\alpha$	275.7 d	6.621 MeV	$\leq 1$ pW	73.21 W	$\leq 1$ pSv	1.932 MSv
<sub>0</sub> <sup>250</sup> Sf	110.9 $\mu$ g										
G <sub>2</sub> <sup>4</sup> He	6.185 gm	1.545 M									
<sup>207</sup> Tl	$\leq 1$ pg	$\leq 1$ pM	1.004 MBq	$7.051 \times 10^9$	$\beta$	4.770 m	495.4 keV	79.68 nW	559.6 kW		
<sup>208</sup> Tl	7.344 pg	$\leq 1$ pM	80.03 MBq	$1.090 \times 10^{10}$	$\beta$	3.053 m	3.971 MeV	50.91 $\mu$ W	6.932 MW		
<sup>209</sup> Tl	$\leq 1$ pg	$\leq 1$ pM	414.8 Bq	$1.514 \times 10^{10}$	$\beta$	2.200 m	2.802 MeV	186.2 pW	6.798 MW		

†First emission from decay with highest branching ratio; ‡Electrorefiner destination: A = anode, C = cathode, E = electrolyte, G = gas

Isotope ‡	Mass grams	Moles	Radioactivity			Half Life	Energy per Bq-s	Thermal Power		Radiotoxicity	
			GBq	GBq/gm	†			Watts	Watts/gm	Sv	Sv/gm
A <sub>81</sub> Tl	7.486 pg	≤ 1 pM	81.03 MBq	1.082×10 <sup>10</sup>				50.99 μW	6.811 MW		
A <sup>217</sup> <sub>85</sub> At	≤ 1 pg	≤ 1 pM	19.20 kBq	5.959×10 <sup>13</sup>	β	32.30 ms	7.198 MeV	22.14 nW	68.72 GW		
<sup>219</sup> Rn	≤ 1 pg	≤ 1 pM	1.007 MBq	4.816×10 <sup>11</sup>	α	3.960 s	6.998 MeV	1.129 μW	539.9 MW		
<sup>220</sup> Rn	6.526 pg	≤ 1 pM	222.8 MBq	3.414×10 <sup>10</sup>	α	55.80 s	6.404 MeV	228.6 μW	35.03 MW		
<sup>222</sup> Rn	45.50 pg	≤ 1 pM	259.1 kBq	5.695×10 <sup>6</sup>	α	3.823 d	5.589 MeV	232.0 nW	5.099 kW		
G <sub>86</sub> Rn	52.03 pg	≤ 1 pM	224.1 MBq	4.307×10 <sup>9</sup>				230.0 μW	4.420 MW		
Total	947.9 kg	3.984 kM	1.040×10 <sup>6</sup>	1.097 GBq				378.2 W	399.0 μW	90.39 MSv	95.36 Sv
ICRP Publication 119 does not report dose factors for isotopes with half lives less than ten minutes or greater than 10 <sup>9</sup> years. Dose factors for gases are given as Sv/day per Bq/m <sup>3</sup> . Radiotoxicity is not computed for gases.											
†First emission from decay with highest branching ratio; ‡Electrorefiner destination: A = anode, C = cathode, E = electrolyte, G = gas											

## Activation Products Per Tonne of Fuel

used for 50.68 GW-day LWR burnup at power of 36.5 MW and  $3.14 \times 10^{14} N/cm^2/s$  neutron flux,  
after fifty years' storage, as calculated by ORIGEN2 version 2.1 on 9 October 2013.  
Radiotoxicity in Sieverts computed for adult ingestion using dose factors from ICRP publication 119

Isotope ‡	Mass grams	Moles	Radioactivity			Half Life	Energy per Bq-s	Thermal Power		Radiotoxicity	
			GBq	GBq/gm	†			Watts	Watts/gm	Sv	Sv/gm
<sup>90</sup> Zr	120.7 kg	1.343 kM									
<sup>91</sup> Zr	26.41 kg	290.5 M									
<sup>92</sup> Zr	41.10 kg	447.2 M									
<sup>93</sup> Zr	160.7 gm	1.730 M	14.94 GBq	92.97 MBq	$\beta$	1.530 My	19.61 keV	46.93 $\mu$ W	292.0 nW	16.43 Sv	102.3 mSv
<sup>94</sup> Zr	42.60 kg	453.6 M	1.000 kBq	23.48 mBq	$2\beta$	6.000 Py	1.144 MeV	183.2 pW	$\leq 1$ pW		
<sup>96</sup> Zr	6.957 kg	72.54 M	24.60 mBq	3.536 $\mu$ Bq	$2\beta$	$\geq 10^{18}$ y	3.350 MeV	$\leq 1$ pW	$\leq 1$ pW		
A <sub>40</sub> Zr	237.9 kg	2.608 kM	14.94 GBq	62.79 kBq				46.93 $\mu$ W	197.2 pW	16.43 Sv	69.07 $\mu$ Sv
<sup>93</sup> Nb	2.509 mg	27.01 $\mu$ M									
<sup>93m</sup> Nb	1.260 mg	13.56 $\mu$ M	13.18 GBq	10.46 TBq	$\gamma$	16.13 y	29.89 keV	63.12 $\mu$ W	50.10 mW	1.582 Sv	1.255 kSv
<sup>94</sup> Nb	63.32 ng	674.3 pM	439.2 Bq	6.936 GBq	$\beta$	19.99 ky	1.718 MeV	120.9 pW	1.909 mW	746.6 nSv	11.79 Sv
A <sub>41</sub> Nb	3.769 mg	40.57 $\mu$ M	13.18 GBq	3.497 TBq				63.12 $\mu$ W	16.75 mW	1.582 Sv	419.6 Sv
<sup>87</sup> Sr	3.321 mg	38.21 $\mu$ M									
<sup>88</sup> Sr	325.3 mg	3.701 mM									
<sup>90</sup> Sr	10.39 $\mu$ g	115.6 nM	52.47 MBq	5.050 TBq	$\beta$	28.79 y	195.8 keV	1.646 $\mu$ W	158.4 mW	1.469 Sv	141.4 kSv
E <sub>38</sub> Sr	328.6 mg	3.739 mM	52.47 MBq	159.7 MBq				1.646 $\mu$ W	5.009 $\mu$ W	1.469 Sv	4.471 Sv
<sup>89</sup> Y	24.79 mg	278.8 $\mu$ M									
<sup>90</sup> Y	2.607 ng	29.00 pM	52.50 MBq	$2.014 \times 10^7$	$\beta$	2.671 d	935.0 keV	7.864 $\mu$ W	3.016 kW	141.8 mSv	54.37 MSv
E <sub>39</sub> Y	24.79 mg	278.8 $\mu$ M	52.50 MBq	2.118 GBq				7.864 $\mu$ W	317.2 $\mu$ W	141.8 mSv	5.718 Sv
<sup>98</sup> Tc	4.887 ng	49.91 pM	157.2 mBq	32.17 MBq	$\beta$	4.200 My	1.532 MeV	$\leq 1$ pW	7.892 $\mu$ W	314.4 pSv	64.33 mSv
<sup>99</sup> Tc	1.152 mg	11.65 $\mu$ M	722.6 kBq	627.3 MBq	$\beta$	214.0 ky	84.61 keV	9.795 nW	8.503 $\mu$ W	462.5 $\mu$ Sv	401.4 mSv
A <sub>43</sub> Tc	1.152 mg	11.65 $\mu$ M	722.6 kBq	627.3 MBq				9.795 nW	8.503 $\mu$ W	462.5 $\mu$ Sv	401.4 mSv
<sup>1</sup> H	12.73 mg	12.63 mM									
<sup>2</sup> H	10.72 $\mu$ g	5.322 $\mu$ M									
<sup>3</sup> H	$\leq 1$ pg	$\leq 1$ pM	153.4 Bq	357.3 TBq	$\beta$	12.33 y	5.680 keV	$\leq 1$ pW	325.2 mW	6.443 nSv	15.01 kSv
G <sub>1</sub> H	12.74 mg	12.64 mM	153.4 Bq	12.04 kBq				$\leq 1$ pW	10.96 pW	6.443 nSv	505.7 nSv
<sup>102</sup> Rh	$\leq 1$ pg	$\leq 1$ pM	158.4 pBq	44.75 TBq	$\epsilon$	2.902 y	2.152 MeV	$\leq 1$ pW	15.43 W	$\leq 1$ pSv	53.69 kSv
<sup>103</sup> Rh	1.108 pg	$\leq 1$ pM									
A <sub>45</sub> Rh	1.108 pg	$\leq 1$ pM	158.4 pBq	143.0 Bq				$\leq 1$ pW	49.29 pW	$\leq 1$ pSv	171.6 nSv
<sup>3</sup> He	6.745 pg	2.236 pM									
<sup>4</sup> He	16.30 mg	4.072 mM									
G <sub>2</sub> He	16.30 mg	4.072 mM									

†First emission from decay with highest branching ratio; ‡Electrorefiner destination: A = anode, C = cathode, E = electrolyte, G = gas

Isotope ‡	Mass grams	Moles	Radioactivity			Half Life	Energy per Bq-s	Thermal Power		Radiotoxicity	
			GBq	GBq/gm	†			Watts	Watts/gm	Sv	Sv/gm
<sup>94</sup> Mo	109.9 pg	1.170 pM									
<sup>95</sup> Mo	29.03 gm	305.9 mM									
<sup>96</sup> Mo	1.824 gm	19.02 mM									
<sup>97</sup> Mo	48.80 gm	503.6 mM									
<sup>98</sup> Mo	616.9 mg	6.301 mM	833.5 mBq	1.351 Bq	2β	100.0 Ty	112.0 keV	≤ 1 pW	≤ 1 pW		
<sup>100</sup> Mo	1.234 μg	12.35 nM	16.50 pBq	13.37 μBq	2β	≥ 10 <sup>18</sup> y	3.034 MeV	≤ 1 pW	≤ 1 pW		
A <sub>42</sub> Mo	80.27 gm	834.8 mM	833.5 mBq	10.38 mBq				≤ 1 pW	≤ 1 pW		
<sup>98</sup> Ru	≤ 1 pg	≤ 1 pM									
<sup>99</sup> Ru	190.5 ng	1.926 nM									
<sup>100</sup> Ru	99.42 μg	995.2 nM									
<sup>101</sup> Ru	500.4 ng	4.959 nM									
<sup>102</sup> Ru	9.511 ng	93.33 pM									
<sup>104</sup> Ru	≤ 1 pg	≤ 1 pM									
A <sub>44</sub> Ru	100.1 μg	1.002 μM									
<sup>104</sup> Pd	≤ 1 pg	≤ 1 pM									
<sup>105</sup> Pd	≤ 1 pg	≤ 1 pM									
<sup>106</sup> Pd	≤ 1 pg	≤ 1 pM									
A <sub>46</sub> Pd	≤ 1 pg	≤ 1 pM									
Total	238.0 kg	2.609 kM	28.23 GBq	118.6 kBq				119.6 μW	502.5 pW	19.63 Sv	82.47 μSv
ICRP Publication 119 does not report dose factors for isotopes with half lives less than ten minutes or greater than 10 <sup>9</sup> years. Dose factors for gases are given as Sv/day per Bq/m <sup>3</sup> . Radiotoxicity is not computed for gases.											
‡First emission from decay with highest branching ratio; †Electrorefiner destination: A = anode, C = cathode, E = electrolyte, G = gas											