

IAEA/ANL
Interregional Training Course



**Technical and Administrative Preparations
Required for Shipment of Research Reactor
Spent Fuel to Its Country of Origin**

Argonne National Laboratory
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Lecture L.3.3

Spent Fuel Classification Data

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MODULE 3:
FUEL CLASSIFICATION

L.3.3
Spent Fuel Classification Data

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Spent Research Reactor Fuel Assembly Properties

- Nuclear Mass Inventory: U, Np, Pu, Am
- Photon Dose Rate
- Thermal Decay Heat

Research Reactor Fuel Assembly Types

- MTR - fuel plates
- TRIGA - fuel rods
- DIDO - fuel annuli

Nuclear Mass Inventory

Mass Inventory: U, Np, Pu, Am MTR-Type Fuel Assembly

- Initial U-235 enrichment: 20, 45, 93%
- Initial U-235 mass: 100 to 500g
- U-235 burnup: 5 to 80%

Mass Inventory: U, Np, Pu, Am TRIGA-Type Fuel Assembly

- Single Rod
 - Initial U-235 enrichment: 20 or 70%
 - Initial U-235 mass: 38 to 133g
 - U-235 burnup: 5 to 60%
- Rod Cluster
 - Initial U-235 enrichment: 20 or 93%
 - Initial U-235 mass: 41 or 54g
 - U-235 burnup: 10 to 60%

Mass Inventory: U, Np, Pu, Am DIDO-Type Fuel Assembly

- Initial U-235 enrichment: 20, 60, 80, 93%
- Initial U-235 mass: 150 or 200g
- U-235 burnup: 10 to 60%

Nuclear Mass Inventory Example MTR-Type Fuel Assembly

U-235 Mass, 300g

U-235 Burnup, 40%

Isotope	U-235 Enrichment		
	20%	45%	93%
U-235	180	180	180
U-236	20	19	19
U-238	1205	361	22
Np-237	0.4	0.4	0.4
Pu-238	0.0	0.0	0.0
Pu-239	7.5	3.4	0.4
Pu-240	1.2	0.6	0.1
Pu-241	0.4	0.2	0.0
Pu-242	0.0	0.0	0.0
Am-241	0.0	0.0	0.0

Photon Dose Rate

Photon Dose Rate Parameters

- Specific Fuel Assembly Power Density:
0.089 to 2.857 MW/kgU-235
- U-235 Burnup: 20 to 80%
- Fission Product Decay Time: 2 to 20 years

Photon Dose Rate Results at 1 m in Air

- MTR -
- TRIGA - 1.04 times MTR
- DIDO - 1.05 times MTR

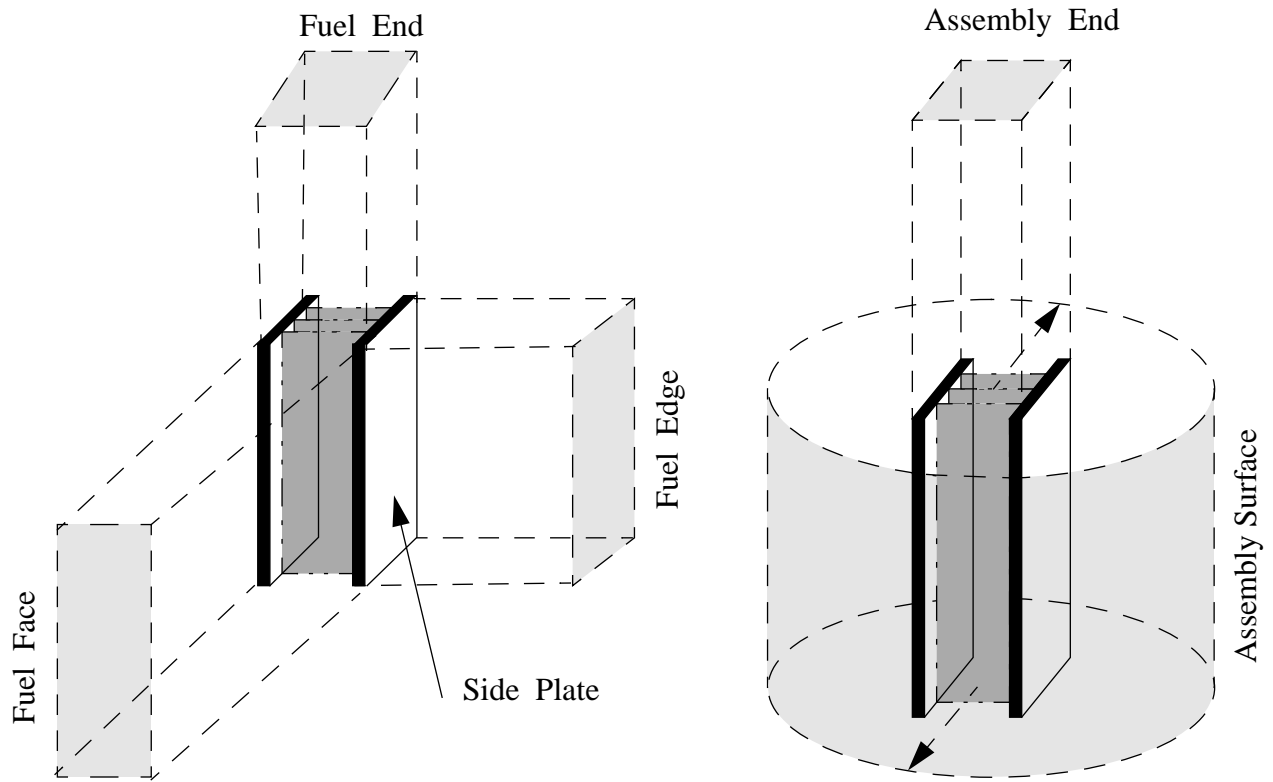


Figure 1. Model of Dose Rate Locations Relative to a Fuel Assembly

Photon Dose Rate Example

Fuel Assembly Data

Time-Average Power	25 kW
U-235 Mass	280 g
Specific Power Density	0.089 MW/kgU-235
U-235 Burned	112 g
U-235 Burnup	40%
Fission Product Decay Time	3 y

Photon Dose Rate Results

FP Dose Rate (Table 8)	1.02 rem/h per gU-235 burned
FA Dose Rate at 1 m in Air	114 rem/h
Self-Protection Time (Fig. 1)	4 y

**Table 8. Photon Dose Rates At 1 M In Air,
rem/h per g²³⁵U burned**

Decay Time, y	Burnup, % ²³⁵ U	Assembly Power Density, MW/kg ²³⁵ U					
		2.857	1.429	0.714	0.357	0.179	0.089
2	1%	1.84+0	1.84+0	1.83+0	1.80+0	1.77+0	1.70+0
3		1.13+0	1.13+0	1.13+0	1.13+0	1.11+0	1.11+0
4		9.01-1	9.01-1	9.01-1	9.01-1	9.01-1	8.92-1
2	10%	1.89+0	1.87+0	1.80+0	1.64+0	1.50+0	1.28+0
3		1.19+0	1.20+0	1.20+0	1.16+0	1.09+0	9.95-1
4		9.52-1	9.61-1	9.61-1	9.44-1	9.10-1	8.59-1
2	20%	2.01+0	1.98+0	1.86+0	1.66+0	1.42+0	1.19+0
3		1.31+0	1.32+0	1.28+0	1.21+0	1.11+0	9.78-1
4		1.04+0	1.05+0	1.04+0	9.99-1	9.44-1	8.63-1
5		8.97-1	9.10-1	9.05-1	8.80-1	8.46-1	7.95-1
10		6.67-1	6.67-1	6.67-1	6.59-1	6.50-1	6.25-1
15		5.78-1	5.78-1	5.74-1	5.70-1	5.61-1	5.44-1
20		5.10-1	5.10-1	5.10-1	5.06-1	4.97-1	4.85-1
2		40%	2.40+0	2.30+0	2.09+0	1.82+0	1.52+0
3	1.62+0		1.60+0	1.53+0	1.39+0	1.22+0	1.02+0
4	1.27+0		1.27+0	1.22+0	1.14+0	1.03+0	8.99-1
5	1.07+0		1.07+0	1.04+0	9.90-1	9.20-1	8.12-1
10	7.03-1		7.03-1	6.95-1	6.80-1	6.55-1	6.10-1
15	5.87-1		5.84-1	5.80-1	5.70-1	5.53-1	5.23-1
20	5.14-1		5.12-1	5.08-1	5.02-1	4.87-1	4.59-1
2	60%		2.95+0	2.79+0	2.52+0	2.15+0	1.74+0
3		2.05+0	2.00+0	1.87+0	1.66+0	1.40+0	1.12+0
4		1.59+0	1.56+0	1.49+0	1.35+0	1.17+0	9.63-1
5		1.30+0	1.29+0	1.24+0	1.15+0	1.02+0	8.54-1
10		7.55-1	7.51-1	7.37-1	7.07-1	6.70-1	6.02-1
15		5.96-1	5.96-1	5.88-1	5.72-1	5.50-1	5.04-1
20		5.17-1	5.17-1	5.13-1	4.99-1	4.76-1	4.39-1
2		80%	3.85+0	3.62+0	3.26+0	2.76+0	2.21+0
3	2.73+0		2.64+0	2.43+0	2.11+0	1.74+0	1.33+0
4	2.08+0		2.03+0	1.90+0	1.69+0	1.41+0	1.12+0
5	1.66+0		1.63+0	1.54+0	1.39+0	1.19+0	9.57-1
10	8.28-1		8.21-1	8.00-1	7.59-1	6.97-1	6.04-1
15	6.18-1		6.15-1	6.05-1	5.82-1	5.44-1	4.87-1
20	5.27-1		5.20-1	5.13-1	4.97-1	4.66-1	4.20-1

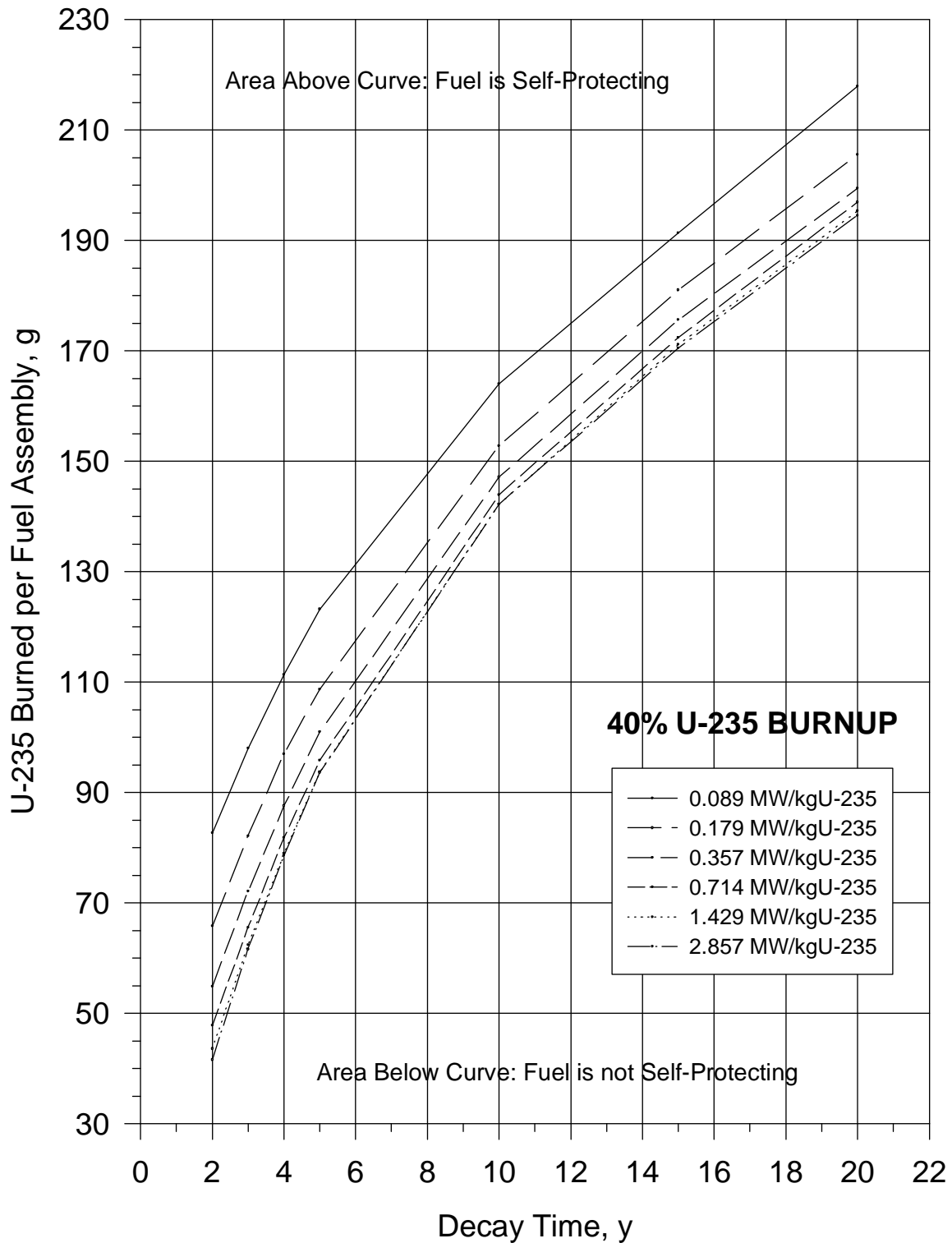


Figure 1. Mass of Burned ^{235}U per Fuel Assembly Necessary for an Unshielded 100 rem/h Dose Rate at 1 m for Fuel Assemblies with 40% ^{235}U Burnup and Power Densities from 0.089 to 2.857 MW/kg ^{235}U

Thermal Decay Heat

Thermal Decay Heat Parameters

- Fuel Assembly Time-Average Power
- Fuel Assembly Elapsed Irradiation Time
- Fission Product Decay Time

Thermal Decay Heat Example

Fuel Assembly Data

Time-Average Power, \bar{P}	25,000 W
U-235 Mass	280 g
U-235 Burnup	40%
U-235 Burned, G	112 g
Fission Product Decay Time, t_d	1095 d
Elapsed Irradiation Time, t_e	3584 d

where $t_e = (G / \bar{P}) / 125 \cdot 10^{-6}$

Thermal Decay Heat Results

ORIGEN	4.2 W
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Eq. -1: Integrated Emission Rates

$H = 685 \cdot 10^{-3} \bar{P} (t_d^{-0.2} - (t_e + t_d)^{-0.2})$	10.6 W
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Eq. -2: El-Wakil

$H = 4.95 \cdot 10^{-3} \bar{P} t_d^{-0.06} (t_d^{-0.2} - (t_e + t_d)^{-0.2})$	5.1 W
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Eq. -3: Untermeyer and Weills

$H = 0.1 \bar{P} [(t_d + 10)^{-0.2} - (t_e + t_d + 10)^{-0.2}]$	
$-0.087 \bar{P} [(t_d + 2 \cdot 10^7)^{-0.2} - (t_e + t_d + 2 \cdot 10^7)^{-0.2}]$	3.8 W

Decay Heat per Unit Power

Irradiation Time = 600 days

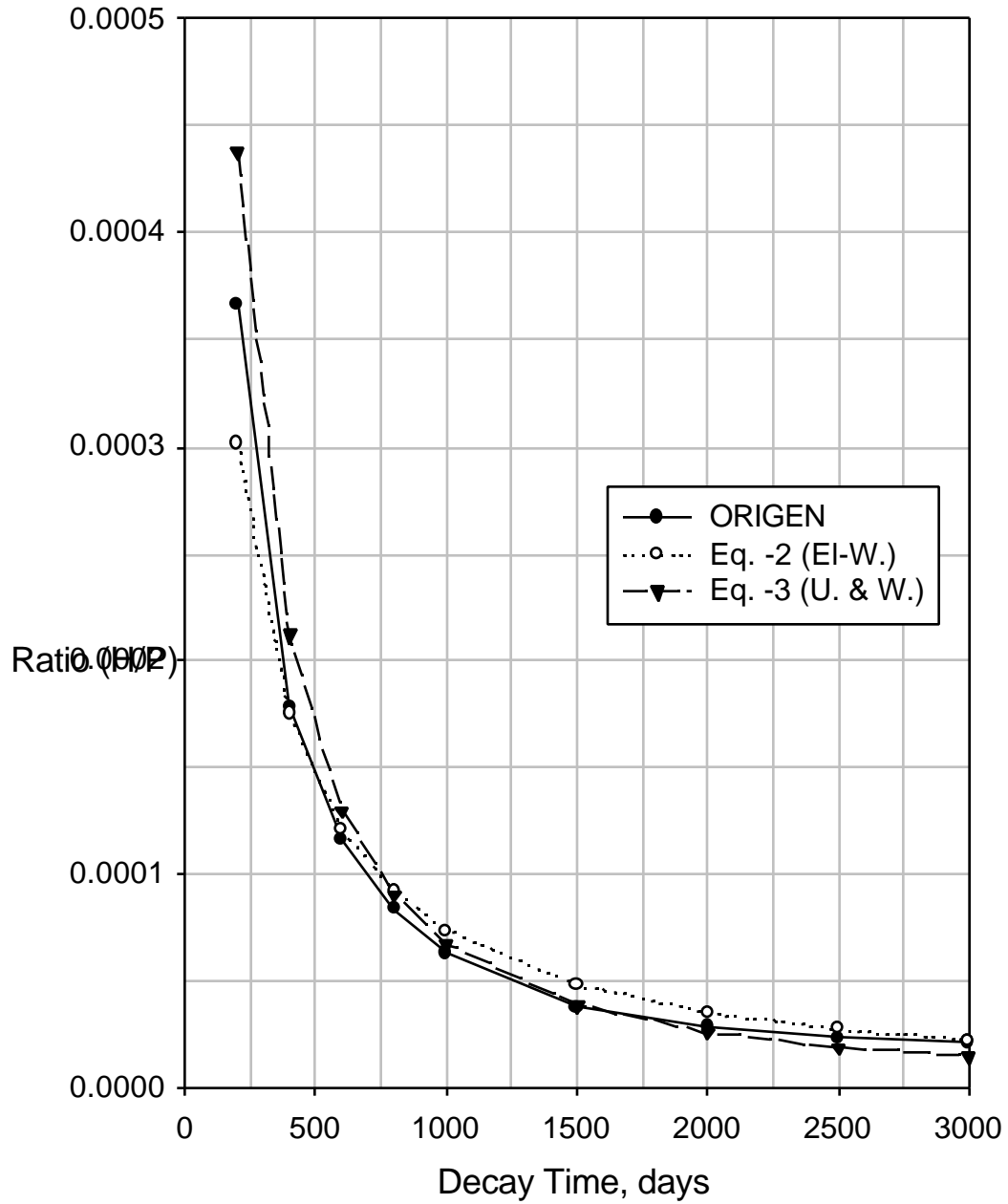


Figure 2. Comparison of Decay Heat Equations-2 and -3 with ORIGEN

PHDOSE Program Package

- Example Input
- Example Output
- Input/Output Description
- PHDOSE Program (Fortran)

PHDOSE Program

- Dose Rate: Line-Source Model of Spent Fuel
 - MTR ~ 0.92 times L-S Dose Rate
 - TRIGA ~ 1.04 times MTR Dose Rate
 - DIDO ~ 1.05 times MTR Dose Rate
- Fission Product Radioactivity (Curies)
- Photon Source (Ph/s)
- Gamma Decay Heat (Watts)

PHDOSE Fission Products

Sr-90	Y-90	Cs-133	Cs-134
Cs-137	Ba-137m	Ce-144	Pr-144
Ru-106	Rh-106	Zr-95	Nb-95

SUMMARY

- Nuclear Mass Inventory
 - Table Look-up
 - Photon Dose Rate
 - Table Look-up
 - PHDOSE Program
 - Thermal Decay Heat
 - Analytical Expression
- PHDOSE Directory: