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Laboratory

Fuel Management for Prismatic HTGR - Example

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Purpose

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As part of the decision-making process for the introduction or expansion of an energy generation technology, fuel supply and management of spent through to final disposal must be understood.

This presentation provides information on the potential scale of spent fuel management activities for HTGRs, to allow comparison with current fuel management operations.

The outputs are intended to provide an indication of similarities and differences between reactor technologies and is not a definitive prediction for any specific reactor deployment scenario.

Prismatic scenarios considered

A high temperature, helium-cooled, graphite moderated, reactor (HTGR) with a core composed of:

- Hexagonal prismatic fuel (in scope)
- Hexagonal prismatic reflector blocks (not in scope)

- Open cycle with
  - Disposal of as-discharged fuel blocks
  - Disposal of separated compacts
- With storage based on three sizes of package

Reactor case

Reference reactor: GTHTR300

Reactor parameters with large impact on the spent fuel management: :

- Maximum enrichment and burn-up of the fuel
- Total number of blocks in the reactor
- Refuelling interval and fraction of the core replaced
- The size and fuel mass and total mass of the blocks
- Capacity of at reactor storage
- Mass and dimensions of packages

Reactor case data

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Reactor Data

Thermal Power	MW	600	[1]
Output power	MWe	274	[1]
	MWh	550	
Average burn-up	GWd/tU	112	[1]
Fuel items per core	-	720	[1]
Operational period	years	60	[1]
Discharge rate	items/y	180	0.5 core every 2 years [1]
annual output	GWDe	85	power output x (days/year) x load factor
	GWDh	171	power output x (days/year) x load factor
Load factor		85%	[3]

Fuel Data

U mass per item	kgU	11.17	-
Total mass per item	kg	181.9	-
Enrichment	%U-235	14%	[1]
Dimensions	geometry	hexagonal	[1]
Diameter	m	0.48	[1]
Height	m	1.00	[1]
Volume	m^3	0.14	-
Output per kgU	GWDe/tU	42.3	-
	GWDh/tU	84.9	-
Output per m^3	GWDe/m^3	3.3	-
	GWDh/m^3	6.7	-

1 Yan, X et al, GTHTR300 design and development. Nuclear Engineering and Design 222, 247-262. 2003
2 ‘Nuclear for Net Zero: A UK whole energy system appriasal’, Energy Systems Catapult, Jun. 2020

Reactor case assessment

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Quantities Discharged

		Annual	Total
number of blocks	-	180	10,935
U mass	teU	2.0	363
volume of fuel	m^3	25.56	2,193
mass of fuel	te	33	5,615

Heat Load Estimate

Average Heat load	1 discharge	Total discharges	
Heat load after 5 years	4,447	1,905	W/teU
Heat load after 50 years	1,335	774	W/teU
LWR 45 GWd/tU at 50 y	1,732	1,130	W/teU

Total heat generation for 60 years discharges		
Heat load after 5 years	692	kW
Heat load after 50 years	281	kW

Fuel Cycle Cases

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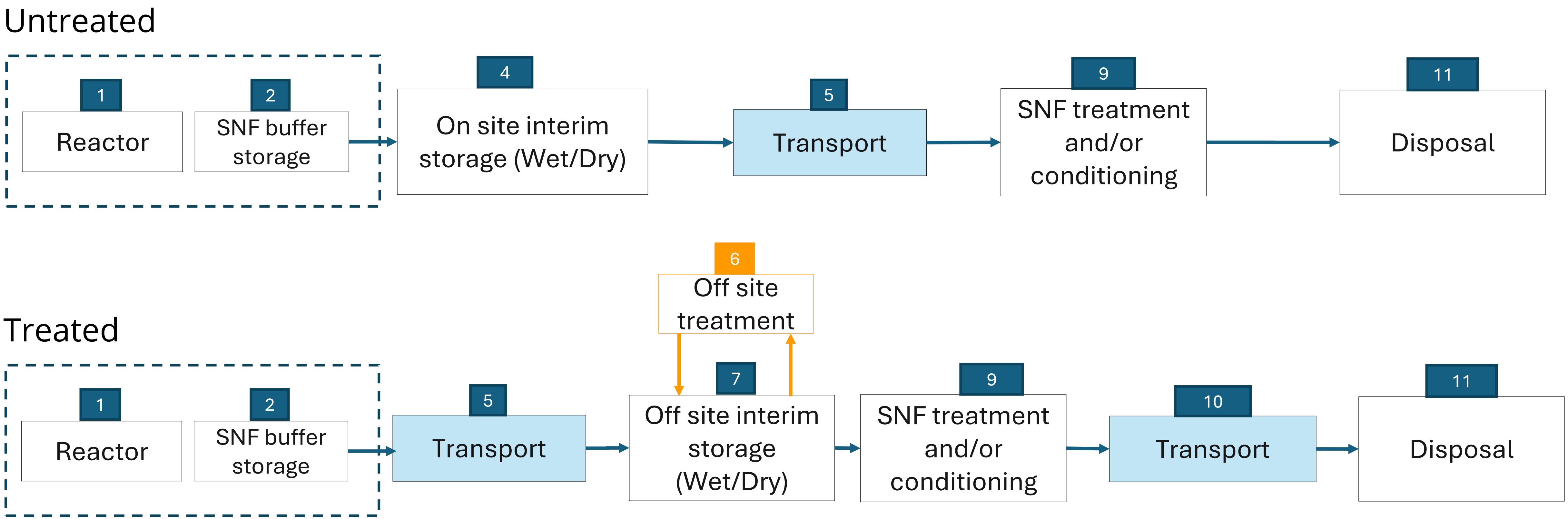

Storage considerations

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Storage parameters with large impact on the spent fuel management:

- Package capacity and maximum heat load
- Package dimension and mass
- Infrastructure limits for size and mass of packages + transporters

Larger capacity means:

- Fewer containers,
- Fewer canister handling operations
- Lower operator dose uptake
- Larger packages, transporters and handling equipment
- Heavier packages and transporters, higher capacity handling equipment
- Larger heat output and surface heat flux

Facilities and infrastructure may have limits for these parameters

Storage cases

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Large package for untreated fuel:

- Based on large LWR canister – HiSTORM100
- Scaled to match an efficient packing of blocks
- *HiSTORM Final Safety Analysis Report, 2016.*

Intermediate package for untreated fuel:

- Based on UK rail/road transportable package for 12 LWR fuel assemblies
- Scaled to match an efficient packing of blocks
- *Contractor Report to RWM Development of a conceptual design of a MPC for PWR Spent Fuel Task 3: Conceptual Design Report.Contractor Report no. Arup/218762-07-01. December 2017.*

Disposal container:

- Based on LWR KBS-3 type container for granitic geology
- Small package for untreated blocks or separated compacts (treated fuel)
- *Contractor Report to RWM Development of a conceptual design of a MPC for PWR Spent Fuel Task 3: Conceptual Design Report.Contractor Report no. Arup/218762-07-01. December 2017*

Storage case data

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Storage Cask		MPC-37	MPC-12	KBS3 type	KBS3 type
Dimensions	units	untreated	untreated	untreated	treated
Length (Diameter)	m	1.90	1.54	1.05	1.05
Height	m	4.35	5.36	4.50	4.50
Volume	m^3	12.33	9.95	3.87	3.87
Mass	kg	17,605	29,729	7,510	7,510
capacity	items	52	35	12	60.1
loaded canister fuel mass	kgU	581	391	134	672
loaded canister mass	kg	27,064	36,096	9,693	13,142
Side area	m^2	26	26	15	15
Fuel mass/side area	teU/m^2	0.022	0.015	0.009	0.045
Storage Overpack					
Dimensions					
Length (Diameter)	m	3.53	-	2.21	2.21
Height	m	5.40	-	4.14	4.14
Volume	m^3	52.85	-	24.20	24.20
Mass	kg	123,722	-	46,158	46,158
capacity	canisters	1	-	1	1
spacing	m	1.76	0.77	1.11	1.11
area	m^2	28	5	11	11

Storage assessment - canisters

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Canister type Fuel condition		MPC-37t untreated	MPC-12 untreated	KBS3 untreated	KBS3 treated-fuel
loaded canister fuel mass	tU	0.58	0.39	0.13	0.67
loaded canister mass	te	18	30	7.5	7.5
number of canisters	y^{-1}	3.5	5.1	15.0	3.0
volume of canisters	m^3	43	51	58	12
mass of canisters	te	61	153	113	22
Electrical output/canister	GWDe	25	17	6	28
Thermal output/canister	GWDh	49	33	11	57
Electrical output/volume	GWDe/m^3	2.0	1.7	1.5	7.3
Thermal output/volume	GWDh/m^3	4.0	3.3	2.9	14.7
Electrical output/mass	GWDe/te	1.4	0.6	0.8	3.8
Thermal output/mass	GWDh/te	2.8	1.1	1.5	7.6
Total number of canisters	per reactor	218	324	945	189
Total volume of canisters	m^3	9,310	16,577	54,857	2,184

Storage assessment - overpacks

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Canister type Fuel condition		MPC-37 untreated	MPC-12 untreated	KBS3 untreated	KBS3 treated-fuel
volume of storage systems	m^3	183	0	363	363
mass of storage systems	te	428	0	692	692
Volume / unit electrical output	m^3/GWDe	2.15	0	4.27	4.27
Volume / unit thermal output	m^3/GWDh	1.07	0	2.13	2.13
Mass / unit electrical output	te/GWDe	5.03	0	8.14	8.14
Mass/ unit thermal output	te/GWDh	2.51	0	4.05	4.05

Transport Fuel

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Transport routes can be

- On-site, with more flexibility for engineering solutions
- Off-site using public transport routes, which will be limited by transport network characteristics, such as axle weight limits or clearance
- Dedicated off-site routes, e.g. dedicated shipping between dedicate shore facilities

- Weight and size of transporter increase with size and mass of packages
- This assessment summarises only package size and mass

Transport data

Canister type Fuel condition		MPC-37 untreated	MPC-12 untreated	KBS3 type untreated	KBS3 type treated
Length (Diameter)	m	2.64	2.23	1.49	1.49
Height	m	5.53	6.05	5.23	5.23
Volume	m^3	30	23	9.1	9.1
mass	kg	123,643	27,370	33,804	33,804
loaded overpack mass	te	153	63	43	47

MPC-37 and MPC-12 use the same shielding thicknesses: 150 mm steel and 60 mm neutron shielding, based on LWR package design

KBS3 type uses UK reference design of transport package, Contractor Report to RWM Development of a conceptual design of a MPC for PWR Spent Fuel Task 3: Conceptual Design Report. Contractor Report no. Arup/218762-07-01. December 2017

Disposal

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Disposal system design is highly dependent on geology

The footprint and volume of material excavated depends on

- disposal architecture
- package design
- heat load

Cooling time for fuel is dependent on surface heat flux and heat load limits

For this illustrative study only a granitic repository has been considered, adapting information for LWR fuel disposal

Disposal Assumptions

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Untreated and treated fuel in KBS-3 type canisters placed vertically in tunnels

		baseline	minimum*
Canister separation distance	m	6.5	2
Tunnel width	m	3	
Tunnel length	m	310	
Tunnel separation	m	25	

RWM. Geological Disposal High Heat Generating Wastes Project: Final Report. NDA/RWM/136, March 2016.
Concept A1: HHGW vertical in parallel tunnels

Disposal Assumptions

Untreated fuel in MPC canisters emplaced in vaults

		max	min
Canister separation distance	m	3.75	1.5
Tunnel width	m	15	-
Tunnel length	m	200	-
Tunnels separation	m	20	15
Tunnel footprint	m^2	7000	6000

RWM. Geological Disposal High Heat Generating Wastes Project: Final Report. NDA/RWM/136, March 2016.
Concept C: wide vault for flask type packages

Surface Heat Flux

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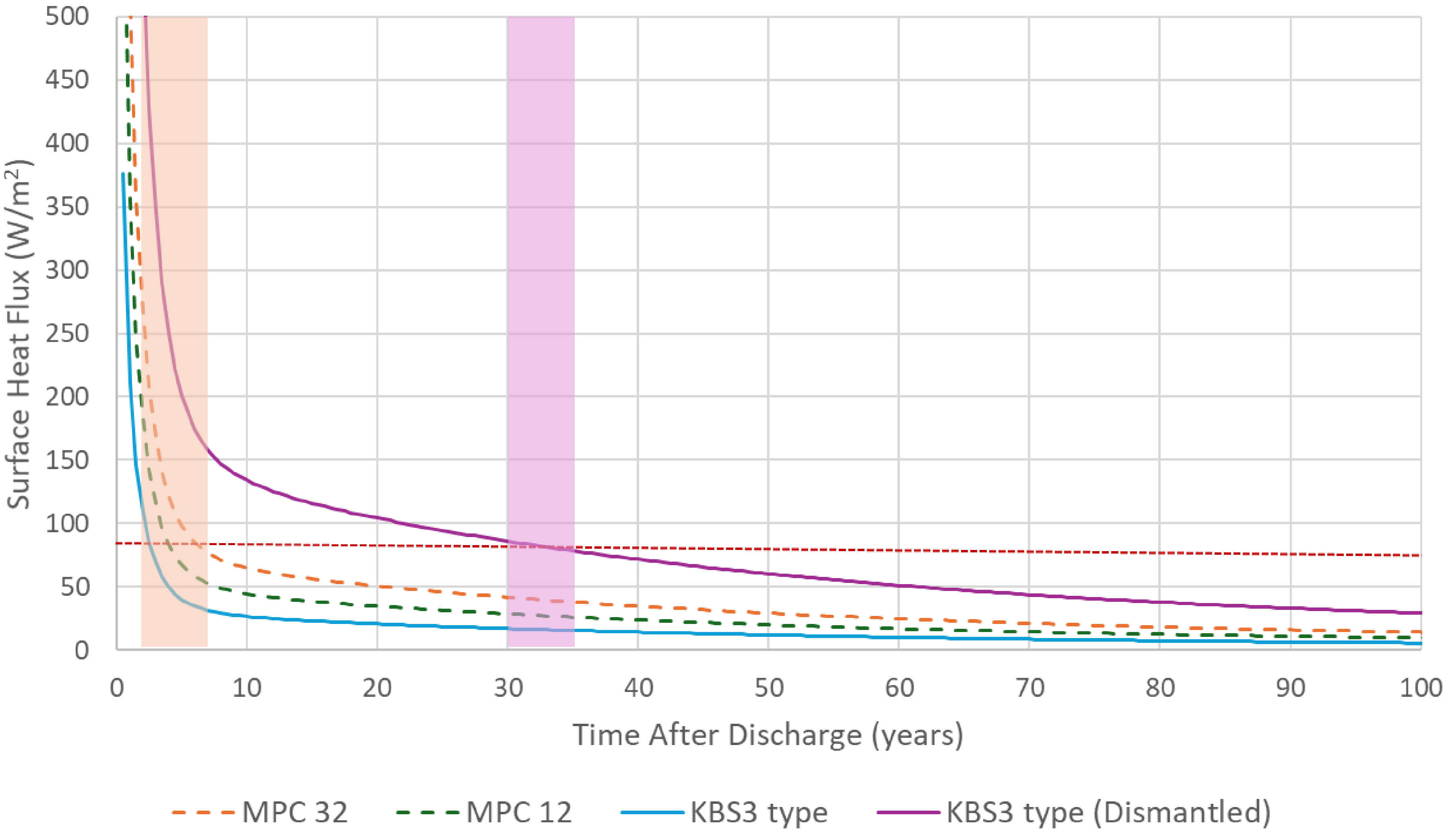

Disposal Assessment

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Canister type		MPC-37	MPC-12	KBS3 type	KBS3 type
Fuel condition		untreated	untreated	untreated	treated
Heat intensity at 5 years	W/m^2	98	103	9	17
Heat intensity at 50 years	W/m^2	40	42	3	7
Canisters across vault	-	3.6	4.4	-	-
Canisters along vault	-	52.3	65.4	-	-
Canisters per vault	-	185.9	290.5	101.0	40.2
Footprint per canister	m^2	32.3	20.7	86.0	215.9
Total footprint	m^2	7,039	6,692	81,227	40,715
Electrical output/volume	$GWDe/m^2$	0.8	0.8	0.1	0.1
Thermal output/volume	$GWDh/m^2$	1.5	1.6	0.1	0.3

Summary

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The volume of fuel generated by a generic HTGR-SMR has been evaluated and normalised to output.

The impact of different canister size and whether prismatic fuel is separated into ILW/LLW blocks and HLW compacts has been evaluated for:

- Numbers of canisters
- Storage space
- Size and mass of transport packages
- Impact on disposability

The assessment is qualitative and intended to illustrate the operational implications of different choices and opportunities to optimise the back end by careful package selection.

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Thank you

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