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How Will Backend Issues Affect The Global Deployment Of SMRs?

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ABSTRACT

There is a growing interest in Small Modular Reactor (SMR) commercialisation, representing a promising pathway towards continued use and/or expansion of nuclear power. Although many challenges must be overcome if the adoption of SMRs is to be widespread, significant interest from global governments, energy providers and other potential users in their development and deployment has led to a "*global race for leadership in the future SMR market*" [1]. One of the key challenges for SMR deployment is ensuring safe and secure radioactive waste management (RWM) where the most challenging task is the implementation of geological disposal for spent nuclear fuel (SNF) in a deep geological repository (DGR) or deep borehole facility (DBF). The key properties of SNF that determine disposal boundary conditions are volume, heat production, fissile material density and physical / chemical characteristics.

Using the open literature, we select credible SMR designs and identify metrics concerning their waste generation. We first use these metrics to explore the potential impacts of SMR deployment on national RWM programmes by illustrating five realistic, but hypothetical, implementation scenarios. We then use these metrics to explore the potential impacts on geological disposal in multinational repository (MNR) projects by developing nine representative scenarios across four varied MNR models. The interim findings of our ongoing study imply that any issues associated with SMR technologies are not insurmountable, if approached in good time prior to SMR deployment. Our interim findings also imply that SMRs could potentially provide a significant driver towards shared approaches to disposal, where challenges primarily appear strategic and socio-political, rather than legal or technical. We are yet to tackle economics in any detail.

1 INTRODUCTION & APPROACH

Whilst significant effort has been made to develop Small Modular Reactor (SMR) technologies, relatively little[1] has been done to understand the impact of SMR deployment on global Radioactive Waste Management (RWM). The management and disposal of radioactive waste is an increasingly important consideration for the expansion of nuclear power[2] and, for

[1] The importance of RWM solutions for the success of SMR commercialisation is highlighted by the publication of new reports in this area, e.g., [16] and [21], since the commencement of our study.

[2] And directly related to one of the eight Generation IV goals, defined by the GIF as: "*Generation IV nuclear energy systems will minimise and manage their nuclear waste and notably reduce the long-term stewardship burden, thereby improving protection for the public health and the environment*" [20].

all countries considering SMRs, safe and affordable spent nuclear fuel (SNF) management solutions must be a key goal.

The purpose of our study is to consider the multinational aspects of the potential technical and strategic, political and commercial impacts of SMR commercialisation on the backend of the nuclear fuel cycle. We explore the heart of the issue by asking:

- **How is global SMR interest manifesting itself in terms of reactor types?** This provides the background for our study and is covered in Section 2 of this paper. We review published literature and news articles to determine national strategic interest and/or financial commitment to SMR designs to focus our study on those which are more credible[3].
- **How would the management of radioactive wastes differ for the deployment of SMRs in comparison to larger, more conventional reactors?** This provides a technical context for our study and is covered in Section 3 of this paper. We focus primarily on disposal and utilise data from the open literature.
- **What impact could SMR deployment have on a national RWM programme?** This is tackled in Section 4 of this paper. We do this by developing representative national profiles and scenarios to look at potential interest in SMRs and how they might be deployed.
- **What impact could SMR deployment have on multinational RWM collaboration and on the potential for future implementation of Multinational Repositories (MNRs)?** This is tackled in Section 5 of this paper. We do this by developing MNR models to assess how different MNR scenarios might be implemented.

2 GLOBAL INTEREST & DEPLOYMENT

Various documents catalogue the SMR designs under development, e.g., [2] and [3]. We identified the most likely near-future deployable SMR designs by reviewing the global end-user landscape. Our summaries of national SMR interest are not presented but cover key countries by global region. Seventeen credible[3] SMR designs were identified, each of which falls into one of five reactor types: Light Water Reactors (LWRs), High Temperature Gas-cooled Reactors (HTGRs), Sodium Fast Reactors (SFRs)[4], Molten Salt Reactors (MSRs) and Heat Pipe-cooled Reactors (HPRs).

To further focus the scope of our study, we down-selected one specific SMR design from our list to represent each of the five reactor types, based primarily on data availability. The down-selected designs are captured in Table 1 with the most current data available[5].

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[3] Credibility refers to the perceived readiness for commercialisation based on published financial/strategic commitment, e.g., collaborative development agreements, direct funding of SMR vendors, not necessarily technical feasibility. China/Russia-based designs/vendors are removed from our scope due to a lack of information and these nations not being seen as potential MNR collaborators.

[4] SFRs are a type of Liquid Metal Reactor (LMR), but all of our identified LMRs use sodium as a coolant.

[5] Efforts were made to supplement the publicly available data with data from vendor organisations.

Table 1: Data for the five down-selected SMR designs, taken from [2, 3, 4, 5, 6, 7, 8, 9, 10].

Design	VOYGR Module	Xe-100	Natrium SMR	IMSR400	eVinci
Type	LWR	HTGR	SFR	MSR	HPR
Power (MWth)	250	200	840	440	7 to 12
Power (MWe)	77	82.5	345	195	2 to 3.5
Fuel	Typical UO_2 pellet in 17x17 array	UCO TRISO particle fuel	HALEU metallic fuel	UF_4 in molten salt coolant	Particle fuel, e.g., TRISO
Enrichment (%)	4.95 (max)	15.5	5 to 20	< 5	5 to 19.75
Burnup (MWd/kg)	45 (min)	165	150-200	14	*Data unavailable*
Vessel Life (Years)	60	60	*Data unavailable*	56	40
Coolant	H_20	Helium	Sodium	Near-eutectic fluoride salt	Sodium-filled heat pipes
Moderator	H_20	Graphite	None	Graphite	Metal hydride

3 RADIOACTIVE WASTE MANAGEMENT

Our study assesses the SMR designs in terms of the following three waste steams: SNF, Operational Waste and Decommissioning Waste.

3.1 Pre-Disposal

Our study considers various pre-disposal backend activities collectively and holistically in terms of 'upstream implications', including storage requirements, conditioning and packaging facilities and transport infrastructure.

3.2 Disposal

The primary focus of our study so far has been on radioactive waste disposal. Furthermore, we focus primarily on SNF. This is because it is the most hazardous waste stream (from the perspective of radioactive safety and security / proliferation) and, once designated a waste, requires geological disposal, whereas other waste streams may not (depending on specific national regulatory, policy and strategic boundary conditions).

Geological disposal refers to the disposal of waste in a Deep Geological Repository (DGR) or Deep Borehole Facility (DBF). A DGR is a facility implemented for the "*disposal of solid radioactive waste*" that is "*located underground in a stable geological formation so as to provide long term containment of the waste and isolation of the waste from the accessible biosphere*". [11] A DBF achieves the same function but using "*specially engineered and purpose drilled boreholes*" which "*offers the prospect of economic disposal on a small scale while, at the same time, meeting all the safety requirements*". [12]

The safe geological disposal of radioactive waste requires a consideration of its 'disposability' (defined in the UK as the "*ability of a waste package to satisfy the defined requirement for disposal*" [13]). Using a UK and an EU example publication [14, 15], we used the properties listed in Table 2 as areas of focus for SMR waste disposability.

Metrics relating to the properties in Table 2 for our five SMR designs are shown in

Table 3, where quantitative data are taken from the open literature[6].

[6] Efforts were made to supplement the publicly available data with data from vendor organisations.

Table 2: Waste stream properties and their relevance when considering geological disposal.

Property	Relevance when considering disposal
Volume	The volume of waste generated by a SMR over its operational lifetime **impacts the size of a DGR/DBF**. DGR/DBF size relates directly to **cost** and other strategic elements, such as **siting**.
Heat Output	The heat output generated by SMR fuel (a function of fuel type, fuel enrichment and fuel burnup) **impacts the size (cost, siting, etc.) of a DGR/DBF** as waste packages with a higher level of thermal activity will require greater spacing between waste packages.
Fissile Material	The amount of fissile material in a SMR waste stream (a function of fuel type, fuel enrichment and fuel burnup) **impacts the size (cost, siting, etc.) of a DGR/DBF** as a greater density of fissile material will require separation across a greater number of waste packages.
Physical Characteristics[7]	The geometry, dimensions and physical form of a SMR waste stream may directly **impact the waste package in which it can be disposed** of and/or **the suitability of a geological disposal concept**.
Chemical Characteristics[7]	The chemical make-up of a SMR waste stream may directly **impact the waste package in which it can be disposed** of and/or **the suitability of a geological disposal concept**.

Table 3: SNF disposability metrics for the down-selected SMR designs. The sources of quantitative data are shown in footnotes. Where no such data is available, the number of red flags provide a proxy for the degree of RWM complexity when compared to SNF from a large PWR for reference (i.e., a likely increase in fissile material or a greater deviation from the physical and chemical form).

Design	Large PWR[8]	VOYGR Module[8, 9]	Xe-100[8]	Natrium SMR[8]	IMSR400[10]	eVinci[11]
Type	LWR	LWR	HTGR	SFR	MSR	HPR
Volume, m^3/GWe-year	9.58	10.4	118	5.56	52.7	118
Decay heat @ 10 years, kw/GWe-year	40.6	42.2	32.2	24.5	24.4	32.2
Decay heat @ 100 years, kw/GWe-year	9.76	10.3	6.36	4.65	5.9	6.36
Waste Packaging[12]	-	-	🚩🚩	🚩	🚩🚩🚩	🚩🚩
Fissile Material[13]	-	-	🚩🚩	🚩🚩🚩	🚩	🚩🚩

[7] In this study, physical and chemical characteristics have been covered more broadly through the consideration of 'Waste Packaging' issues and concerns.

[8] All quantitative data is taken from [16].

[9] 50, 60 and 77 MWe versions are referenced in open literature, but 77 MWe design data is shown.

[10] Waste Volume / Heat Output are, respectively, calculated as ~5.5 / ~0.6 times that of a Ref PWR in [17]. A single scaling factor for heat output for both 10 and 100 years further compounds uncertainties.

[11] Xe-100 data is used given similar particle fuels. The 5-19.75% enrichment range for eVinci covers the Xe-100 enrichment of 15.5%, but the lack of eVinci burnup data further compounds uncertainties.

[12] Little quantitative data on the physical/chemical characteristics of SMR SNF was available. Arguments regarding the impact of physical/chemical characteristics on waste packaging led to the use of flags.

[13] Data concerning fissile material and/or criticality safety calculated in [17] is not transferable to all five SMRs. Given no other available data, arguments regarding fissile content led to the use of flags.

4 IMPACT ON NATIONAL WASTE MANAGEMENT

We assess potential impacts of SMR deployment on generic national power generation portfolios by illustrating five generic categories to represent theoretical countries (OneLand is a theoretical Category 1 country, etc.) interested in utilising SMRs. Key differentiators are size and diversity of any existing radioactive waste inventory, commitments to radioactive waste disposal, the existence of a native SMR vendor (or not) and the availability of relevant RWM expertise, capability, and infrastructure. Example countries for each category are included, but no direct mapping is made as each country's approach to nuclear power and RWM is unique.

A **Category 1** country has a large nuclear power programme, a highly diverse radioactive waste inventory and an established strategy and/or programme for radioactive waste disposal. It has a potential interest in developing new nuclear power and a national SMR vendor. It also has considerable fuel cycle facilities with world-leading fuel cycle expertise.[14] Example category 1 countries are Canada, France, UK and USA. For our scenarios, **OneLand** has 40 GWe of installed nuclear capacity but is interested in increasing this by ~12 GWe.

A **Category 2** country has a medium nuclear power programme, a relatively uniform radioactive waste inventory and an established strategy and/or programme for radioactive waste disposal. It has a potential interest in developing new nuclear power and has various fuel cycle facilities with appropriate accompanying expertise. Example Category 2 countries include Belgium, Finland, Japan and Sweden. For our scenarios, **TwoLand** has 15 GWe of installed nuclear capacity and is interested in SMRs as a source of an additional ~6 GWe to facilitate remote mining operations.

A **Category 3** country has a small nuclear power programme, a relatively uniform radioactive waste inventory and an established strategy and/or programme for radioactive waste disposal. It has a potential interest in developing new nuclear power but has limited fuel cycle facilities and expertise, primarily focused on storage of SNF on-site following removal from nuclear power reactors. Example Category 3 countries include Croatia / Slovenia, Czechia, Mexico, Netherlands and South Africa. For our scenarios, **ThreeLand** has 2 GWe of installed nuclear capacity and wishes to meet the additional ~3 GWe in demand for electricity, district heating and powering commercial ships.

A **Category 4** country has research reactor(s) or other R&D facilities, but no nuclear power programme. However, it has a strong interest in developing a large and ambitious nuclear power programme. Example Category 4 countries include Poland and Saudi Arabia. For our scenarios, **FourLand** has no installed nuclear capacity but is considering ~18 GWe of nuclear capacity to become self-sufficient but meet emissions targets.

A **Category 5** country has no nuclear power programme, but a potential interest in developing a limited nuclear power programme by building on the expertise acquired through existing research reactors(s) or other nuclear R&D facilities. Example Category 5 countries include Australia, Denmark, Estonia, Jordan and Norway. For our scenarios, **FiveLand** sees SMRs as a low-risk option for its first nuclear power, eyeing an initial capacity of ~1.5 GWe.

4.1 Interim Results & Conclusions

We use the metrics in

Table 3 to consider how each of the five representative countries would be impacted if they were to use each of the five down-selected SMR designs to provide the target additional capacity. Calculations are not shown here, but interim results and conclusions are discussed in Section 4.1.1 and 4.1.2.

[14] This does not explicitly include spent fuel reprocessing facilities/expertise as only France holds this capability. However, it does assume a strong position from which to establish a reprocessing capability.

4.1.1 Inventory size and diversity (Disposal) implications

We observe that the implications of accepting SMR operational and decommissioning low- and intermediate-level waste into a national RWM programme are small. Such wastes only become an issue for new nuclear programmes and, except for graphite reactor core wastes (e.g., from the Xe-100 and eVinci particle fuels), do not represent difficulties that are new to the field of RWM. Consequently, we have focussed on the management and disposal of SNF from SMRs, which is the most differentiating in terms of potential impacts.

Countries with large to medium sized nuclear power programmes, such as OneLand and TwoLand, are likely to have mature DGR programmes that can readily absorb the additional wastes from even relatively large power capacity increases from deployment of multiple SMRs. For these nations, there are no specific drivers towards opting for an MNR rather than a national DGR that arise specifically due to SMRs. However, if an appropriate operational MNR existed, this could be an attractive option should their chosen SMR design(s) generate exotic wastes not included in their existing radioactive waste inventory for disposal.

For countries in categories 3,4, and 5, the deployment of SMRs of identical or similar designs could be an incentive for enhancing cooperation on pre-disposal and disposal activities, providing unique resource-pooling and economy of scale opportunities.

In contrast, non-nuclear nations such as FiveLand would be strongly motivated to seek MNR solutions and are the most likely to be responsive to market-led solutions, such as take-back offers (vendors offering to take SMRs / SNF back after operations). It is also reasonable to assume that countries in this category would be most likely to embark on a nuclear power programme through the use of SMRs, rather than by building a single large conventional nuclear power plant.

Noting potential security challenges, a take-back scenario might be of mutual benefit for a Category 1 or 2 country with a national SMR vendor taking back waste from one or more Category 4 or 5 countries. For the Category 1 or 2 country, this would mean an existence of market advantage and, for the Category 4 or 5 countries, easier solutions to backend issues.

4.1.2 Upstream (Pre-Disposal) implications

In any country with significant existing nuclear power (i.e., Categories 1 to 3), inventory diversity and fuel cycle infrastructure drivers mean that it is likely to be more cost efficient for SMR technologies to align closely with existing national nuclear technologies.

Conversely, FourLand may be the most likely to have drivers towards being a new technology leader for SMR implementation and the disposal of SMR SNF. With large-scale ambitions to deploy many SMRs for multiple purposes, it is likely that Category 4 countries would include several SMR technologies in their power portfolios. Here, the ambitious approach may make less conventional technologies more viable given an appropriate, and significant, level of investment, should the case for that specific technology be particularly attractive.

The option to use DBF rather than DGR solutions is likely to be most attractive to FiveLand as it might be deployed more flexibly than through scheduling/strategy alignment with a MNR facility. As with SNF take-back, security challenges remain a key complexity.

5 MULTINATIONAL REPOSITORY MODELS & SCENARIOS

We aim at a high-level assessment of SMR deployment impacts on MNR development and operation by presenting nine MNR scenarios using four MNR Models. These MNR models and scenarios, summarised in Table 4, were developed to examine the impact of different SMR designs on different combinations of different categories of country.

Table 4: MNR model and scenarios developed for, and used in, our study.

MNR Model	MNR Scenarios
A: New-nuclear MNR. Small countries currently without nuclear power or previous RWM experience, situated relatively close together, agree to share a repository. ***Installed + Required Additional capacity: 0 + 4.5 = 4.5 GWe***	**A1:** An MNR agreement is reached prior to nuclear reactor selection, leading participating nations to introduce the same large PWR design (i.e., no SMRs).
	A2: An MNR agreement is reached prior to nuclear reactor selection, leading nations to introduce the same SMR design; the VOYGR Power Module.
B: Shared MNR. Partner countries (e.g., the ERDO Association member nations) collaborate to share a single MNR hosted in one of their countries. ***Installed + Required Additional capacity: 19 + 33 = 52 GWe***	**B3:** An MNR agreement is reached prior to nuclear reactor selection, enabling alignment of SMR designs introduced by ‘new nuclear’ countries with operational large LWR designs in ‘established nuclear’ countries, leading all nations to introduce the same SMR design; the VOYGR Power Module.
	B4: Nuclear reactor selection is initiated prior to an MNR agreement, leading to a nation-by-nation approach, where ‘established nuclear’ countries introduce the same SMR design; the VOYGR Power Module, to align with their operational large LWR designs, but ‘new nuclear’ countries opt for a more exotic SMR design; the Natrium SMR.
C: SMR Vendor Nation-hosted Commercial MNR. An SMR vendor nation develops a DGR for its national waste and accepts waste generated by users of the SMR. ***Installed + Required Additional capacity: 59 + 45 = 104 GWe***	**C5:** The commercial nature of the MNR motivates the adoption of the vendor SMR design, where all nations introduce the same SMR design; the VOYGR Power Module.
	C6: The commercial nature of the MNR motivates adoption of the vendor SMR design, where all nations introduce the same SMR design; the Xe-100.
	C7: The commercial nature of the MNR motivates adoption of the vendor SMR design, where all nations introduce the same SMR design; the Natrium SMR.
D: Non-SMR Vendor Nation-hosted Commercial MNR. A nation without an SMR vendor acts as an MNR vendor, providing a disposal solution for a group of nations (e.g., all of the ERDO Association member nations). ***Installed + Required Additional capacity: 19 + 34.5 = 53.5 GWe***	**D8:** An MNR agreement is reached prior to SMR selection, enabling alignment, leading all nations to introduce the same SMR design; the VOYGR Power Module.
	D9: SMR selection is initiated prior to an MNR agreement, leading to a nation-by-nation approach, leading to a broad mix of SMR designs across the five categories.

5.1 Interim Results & Conclusions

We use the metrics in

Table 3 to consider how each of our MNR scenarios would be impacted, considering disposability; research, development and demonstration (RD&D); and upstream perspectives. Calculations are not shown here, but interim results and conclusions are discussed in Sections 5.1.1 to 5.1.5.

5.1.1 Technical implications for MNRs

The technical implications of accepting SMR SNF into an existing geological disposal programme are mostly the same whether a national DGR or an MNR. The introduction of SMRs that share a reactor type with any existing reactors results in no strong or new technical motivation towards shared disposal. The introduction of Natrium SMR SNF (with a comparatively high fissile material density) is expected to remain manageable for an MNR project. Assuming direct SNF disposal, spent Xe-100 or eVinci particle fuels could result in a large SNF volume increase that could dominate other MNR design considerations. SNF from only a moderate number of Xe-100 or eVinci SMRs could become a major issue for an MNR project. Reprocessing solutions could mitigate this volume concern, but reprocessing is challenging, and particularly so for particle fuels. A lack of commercial solutions for processing IMSR400 SNF into a stable waste form makes it a challenging design. Significant investment would likely be required to develop backend solutions, e.g., the synthetic rock process under investigation by Terrestrial Energy Inc. [18], in any scenario where MSRs are deployed.

Our scenarios do not account for timing/scheduling considerations. The most straightforward MNR approach involves users defining a clear programme for SMR introduction, along with the timescale over which they will come on-line, with pre-selected technologies, prior to MNR development. This is most likely to occur for a shared MNR developed progressively by a long-standing partnership of users in Category 4 and 5 countries (e.g., the ERDO Association). The most problematic scenario is likely to be one where an MNR is subject to interest from new users, who independently decide on SMR numbers, technologies and start dates, at a point where the MNR is about to become operational for committed wastes of existing users. This is most likely to arise for a commercial MNR.

Countries working together on MNR development are likely to be motivated to use a small number of different SMR technologies and attempt to optimise their SMR deployment scheduling, although this motivation will not necessarily be strong enough to override other factors in SMR choice. It will be particularly important to design a system that can handle a wide range of SMR waste for any commercial MNR. Additional up-front costs when compared to adopting an existing DGR design, safety case and operational procedures can be expected.

SMR SNF will certainly affect the design and management of an MNR project, but its inclusion along with other committed wastes from national nuclear power programmes seems unlikely to introduce difficulties that are significant enough to discourage MNR development. Should multiple MNR users be interested in a particular SMR technology, it might ease the decision to deploy SMRs if a common solution is being investigated, rather than a country 'going-it-alone'. In this case, involvement in an MNR project could be attractive.

5.1.2 MNR through partnership (MNR Models A & B)

Extensive work has been carried out on this by the Arius and ERDO Associations. Implementing MNRs through the partnering of smaller countries has been supported by the EU through its promotion of the potential benefits of regional solutions, i.e., facilities shared by Member States. From a legal perspective, licensing regime harmonisation could facilitate backend collaboration and cooperation activities, where made viable by shared interest.

The growing interest in SMRs may have direct impacts on this approach by, for example, expanding ERDO Association membership, as more countries consider introducing nuclear power by acquiring SMRs; encouraging the establishment of 'sister organisations' to the ERDO Association in other regions; incentivising potential MNR partners to coordinate their SMR design selection; and diversifying MNR concepts to include DBFs, which may be a disposal solution applicable for countries with only a small number of SMRs.

5.1.3 Take-back for MNR disposal (MNR Models C or D)

The offer of waste take-back may mean that countries without nuclear power are more likely to consider SMRs. Historically, nuclear power plant vendors have had little interest in addressing waste disposal. RWM has not been part of the business model of nuclear power vendors.

SMR vendors could regard 'the disposal issue' as either a problem or an opportunity. Returning SMR SNF would be attractive to user nations strategically, politically and possibly economically, but the vendor nation would need to be willing to dispose of this waste. Take-back could be viable for vendor nations with a disposal solution, however: the national policy and legislation of the vendor country would need to allow for import of radioactive waste for disposal; the legal and commercial mechanisms would need to be established to allow the SMR vendor to either become a partner in, or additional user of, the national disposal facility; and the socio-political and legal issues of accepting returned, 'foreign' wastes into a national disposal facility would need to be dealt with. If take-back were restricted to SNF, then the socio-political aspect might be more readily overcome, especially if the vendor country were also offering fuel recycling services. A plausible model might be found in the well-established solutions for research reactor SNF in research reactor vendor countries (e.g., USA).

5.1.4 SMR vendor as MNR developer (MNR Model C)

If one or more SMR vendors considered the take-back solution viable, they may be able to partner with a country (an SMR customer being most likely) to develop an MNR project and offer a complete SMR lifecycle service. No MNR projects are currently underway, but in the context of today's enthusiasm for SMR development it can be envisaged that SMR vendors might be proactively supported by the government in a potential SMR user nation.

In business and commercial terms, becoming involved as the prime developer of an MNR would be a major commitment for an SMR vendor. For an existing MNR project, e.g., where the ERDO Association nations decided to develop an MNR in one of their territories, the SMR vendor risks would be much reduced. The involvement of one or more SMR vendor in MNR design, financing and licensing would benefit all project participants. A first step might involve SMR suppliers - especially those with novel fuel cycles, building multinational 'user groups' with an initial goal of using the same design to cooperate on SNF pre-disposal activities.

5.1.5 Commercial disposal service (MNR Models C or D)

A scenario can be conceived where a competent organisation sees a marketing opportunity for providing a global service. A major study in Australia examined this option over 20 years ago and the South Australian state government took the analyses further in 2016. This is also an active area of work at the International Atomic Energy Agency (IAEA). In each case the focus is on large reactor wastes, but SMR-specific considerations include:

- **The potential customer base.** More than half of the countries with nuclear power have small programmes. Should SMRs see wide deployment, the number of countries with relatively small quantities of SNF and high-level waste would potentially grow significantly, hence an increased interest in MNRs as an economic alternative to a small, national DGR.
- **MNR interest.** Global interest in MNRs was present prior to the upsurge in SMR interest. In Europe, around half of the national reports submitted to the EC under the Waste Directive make some reference to multinational disposal or 'dual track' approaches. The MNR user base can be expected to increase following any large-scale SMR deployment.
- **Drivers for exporting wastes.** Currently, under the IAEA's Joint Convention [19], the country that discharges SNF and receives the benefits of the power generated bears the responsibility for its management, including disposal. The only permanent solution is geological disposal, hence, the only permanent alternative to an MNR is a national DGR or DBF, even for nations with a very small radioactive waste inventory requiring disposal.

6 ADDITIONAL WORK

Our focus has primarily been on the direct disposal of SNF, but we consider the potential impact of SNF reprocessing in our discussions. We primarily cover disposal, but plan to assess upstream implications in more detail and aim to cover operational / decommissioning wastes further. We primarily focus on DGRs but will include a section on DBFs in our final report.

Few quantitative data on SMR wastes are available in the open literature, but those available have been sufficient for our broad / generic category / scenario analysis and general conclusions. we will continue to monitor publications / reach out to vendors to ensure that we continue to use the most accurate / up to date information available.

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