Examining Supply Chain Resilience for the Intermodal Shipment of Spent Nuclear Fuel and High Level Radioactive Materials-16309

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ABSTRACT

The U.S. Department of Energy (DOE) has a significant programmatic interest in the safe and secure routing and transportation of Spent Nuclear Fuel (SNF) and High Level Waste (HLW) in the United States, including shipments entering the country from locations outside U.S borders. In any shipment of SNF/HLW, there are multiple "chains;" a jurisdictional chain as the material moves between jurisdictions (state, federal, tribal, administrative), a physical supply chain (which mode), as well as a custody chain (which stakeholder is in charge/possession) of the materials being transported. Given these interconnected networks, there lies vulnerabilities, whether in lack of communication between interested stakeholders or physical vulnerabilities such as interdiction. By identifying key links and nodes as well as administrative weaknesses, decisions can be made to "harden" the physical network and improve communication between stakeholders. This paper examines the parallel chains of oversight and custody as well as the chain of stakeholder interests for the shipments of SNF/HLW and the potential impacts on systemic resiliency. Using the Crystal River shutdown location as well as a hypothetical international shipment brought into the United States, this paper illustrates the parallel chains and maps them out visually.

INTRODUCTION

The U.S. Department of Energy (DOE) has a significant programmatic interest in the safe and secure routing and transportation of spent nuclear fuel and other radioactive materials in the United States including shipments entering the country from origins outside US borders. While DOE has expressed a preference for spent nuclear fuel (SNF) to be shipped by railcar [1], the locations of various nuclear power plants in the US, as well as the prospect of handling foreign radiological wastes through US ports, preclude the use of the rail mode exclusively for many prospective high level waste (HLW) shipments. As a result of these factors, it is highly likely that some type of intermodal transportation solution will be required to move SNF or HLW from their origin locations to their ultimate destinations. A considerable challenge then arises from the multijurisdictional nature of the applicable laws and associated regulatory agency oversight that may affect the routing and transportation of SNF and HLW across multiple transport modes. Further this jurisdictional chain of oversight exists alongside, and impacts, the custodial nature of the physical SNF/HLW supply chain involving the railroads, trucking companies, and maritime/waterways shipping companies. In addition, the regulations for SNF and HLW also recognize a stakeholder chain of affected or interested parties such as states, localities, port authorities, and tribal governments. Cutting across these multiple chains of interest, oversight and custody are further impacts resulting from the competing and complementary focal points of safety and security from the standpoint of both population exposure and critical infrastructure vulnerability.

Modern supply chains are comprised of interconnected, yet separate, physical modal transport networks. Safe, secure, and efficient intermodal transportation relies upon the smooth transfer of custody of materials in transit at facilities and terminals that serve as connectors between modes. However, these interconnected network systems are vulnerable when there are disruptions to one or more of the modal networks which have spillover effects on the other transport modes. If these disruptions are of sufficient extent or duration, the resiliency and flexibility of the existing network may be compromised by potentially taxing the available network capacity of the alternate modes. While many situations only involve local network disruptions, particularly critical locations that face interdiction may lead to a severe degradation of regional or national multimodal freight mobility.

Understanding the potential spillover impacts on interrelated transportation networks from interdiction events (either natural or man-made) is vital for planning and operating transportation systems [2]. By identifying key links and nodes in these structures, decisions can be made to prioritize capital investment to "harden" those network components most critical to multimodal network efficiency and thereby improving the resiliency of the freight system.

In a similar fashion, intermodal transportation relies upon legal and regulatory stability and clarity. If the jurisdictional chain is also subject to disruption due to either a legal or regulatory conflict, or due to the partial or complete collapse of a regulatory agency in the event of a disruptive event, the transportation system could be subject to impacts similar to an actual, physical disruption. Oversight coordination across and between agencies in the jurisdictional chain is therefore critical to the operational coordination in the physical supply chain.

This study examines the parallel chains of oversight and custody as well as the chain of stakeholder interests for the shipment of SNF/HLW and the potential impacts on systemic resiliency. Particular routes and modes are analyzed to provide insight into the variety of interactions between the jurisdictional and supply chains for shipments of SNF/HLW. For illustrative purposes a set of representative origins and destinations was selected from the various shut down reactor sites within the United States and one route modeling the entry of foreign HLW through a US port.

By its very nature freight transportation is multi-jurisdictional. From interstate transport, to international transport, and transportation across and between modes, freight traverses international, federal, state and local boundaries as goods moves from origins to destinations. In addition to this physical reality, freight traverses and moves through an equally real administrative and legal landscape populated by various laws and regulatory bodies to enforce them.

MAPPING THE LEGAL GEOGRAPHY OF SNF/HLW TRANSPORT

From the perspective of the legal requirements in transporting SNF/HLW in the United States and internationally, there exists a complex tapestry of statutes and regulations which delineate the standards, controls, procedures, as well as the agencies and jurisdictional stakeholders (states, localities, and tribal entities) who are impact by transportation of these hazardous materials through their respective jurisdictions. While the number of statutes governing SNF/HLW is limited to a handful, the level of overlapping agency involvement and jurisdictional issues becomes complex and unwieldy. As Kassen [3] points out, while there is "jurisdictional friction" in non-hazardous material transportation, given the specialized knowledge required for moving SNF/HLW, more agencies are involved, namely DOE, the US Nuclear Regulatory Commission (NRC) and the US Department of Transportation (DOT). In addition to these agencies, additional concerns of health, safety, and environmental protection, prerogatives usually asserted by the Occupational Safety and Health Administration (OSHA), Environmental Protection Agency (EPA), and the Federal Emergency Management Agency (FEMA) are implicated.

Similar to mapping the supply chain and the individuals handling the material at any given point through a given transport of SNF/HLW material, so too can one map the legal geography of the statutes, regulations, and agencies involved. This section will provide a brief background as to the various statutory and regulatory provisions associated with the transportation of SNF/HLW, acknowledging the various modal agencies and potential statutes that are implicated not originally considered associated with SNF/HLW transport.

Material Specific Statutes: NWPA and HMTA

Conceptually, the transportation of any good, including hazardous materials such as SNF/HLW material, begins with an origin and ends with a destination. At any given point along the route, the vehicle may move through various localities, states, tribal lands. From a modal perspective, when containers are offloaded from a vessel and loaded onto road or rail modes, the administrative agencies that "monitor" their transit change as well. However, with SNF/HLW, there are two statutes that regardless of their geographic position or mode of transit are active from origin to destination. These statutes are the Hazardous Materials Transportation Control Act (HMTA) of 1975 [4] and the Nuclear Waste Policy Act (NWPA) of 1982 [5]. As Giglio [6] explains, the HMTA was passed in 1975 with Congress delegating the Secretary of Transportation federal authority to regulate the transportation of radioactive materials, including SNF/HLW. Under various sections of the HMTA, various modal agencies (FHWA, FRA, Federal Aviation Administration, and the United States Coast Guard (USCG)) are delegated responsibility for regulating transport of radioactive material for their area of modal expertise. In addition to the statutory provisions, HMTA provides regulatory guidance for policy, materials, packaging, and operational procedures related to SNF/HLW transport under various sections of Chapter 49 of the Code of Federal Regulations (CFR). With respect to transportation CFR sections 174-177 [7][8][9][10] delineate specific responsibilities for the various modes that may be chosen to move the radioactive material. When HMTA was passed, Congress delegated sole authority to the DOT, but as Kassen [3] explains, DOT lacks subject matter expertise with regard to nuclear safety and the nuances of radioactive material. Subsequent to HMTA passage, DOT through various memorandums of understanding (MOUs) delegated their authority under the HMTA to both the DOE and the NRC in order to address overlapping statutory responsibilities. For example, the HMTA regulates all hazardous materials transportation, including Class 7 radioactive materials, while the Atomic Energy Act (AEA) of 1954 [11], regulates all radioactive materials. A 1979 MOU between DOT and NRC delineates and clarifies the specific roles and responsibilities for radioactive materials transport under the separate acts [12]. Because of NRC's statutory authority and delegation under the AEA as well as DOE control under NWPA to manage the "safe storage and/or disposal of radioactive waste" [13], various other regulatory provisions, namely 10 CFR § 73.37 [13], addressing the physical protection of irradiated fuel in transit have bearing. Under these regulatory provisions, the NRC delineates the various security features required for irradiated fuel depending on the mode chosen. In each modal option, the regulations outline the necessary number of security personnel, the type of radio equipment needed, as well as coordination with state, local, and tribal partners to ensure impacted communities are aware of the irradiated fuel moving through their jurisdiction [15][16].

From a visualization perspective (see Figure 1, below), statutes such as the AEA, NWPA, HMTA, and its successor legislation, the Hazardous Material Transportation Uniform Safety Act (HMTUSA) [17] are present throughout the supply chain for transporting SNF/HLW. Regardless of the mode choice for moving the material or the various locations or routes that the material may take to depart from the origin of the shutdown site to its destination at a repository, these laws will be in place throughout the trip. Likewise, regulatory provisions found in Titles 10 and 49 of the CFR stay with the material throughout the journey, meaning that whatever mode, wherever the load is, these regulatory provisions are in effect. However, while certain statutory provisions are constant throughout the transport of SNF/HLW, depending on the mode selected and the location of given facilities, additional statutes, and regulations may be involved.

Modal Specific Statutes and Regulations

Within the regulatory provisions of the HMTA, namely Title 49 Parts 174-177, the regulations describe the operational requirements for transporting hazardous materials by rail, air, water, and road. Similar requirements can be found in Title 10 part 73.37. With particular modes, administrations of the DOT that were delegated responsibility under HMTA take lead on inspecting routes and ensuring compliance with appropriate regulatory requirements. Such inspection reviews the geographic route(s), who to notify in case of an emergency, instructions for on-scene emergency coordinators, emergency response team instructions, as well as first aid measures [15]. In addition to FRA regulatory oversight for rail transport of SNF/HLW, PHMSA also has regulatory oversight to ensure that the routes chosen are safe, as well as to ensure proper safety procedures and placarding are in place [17].

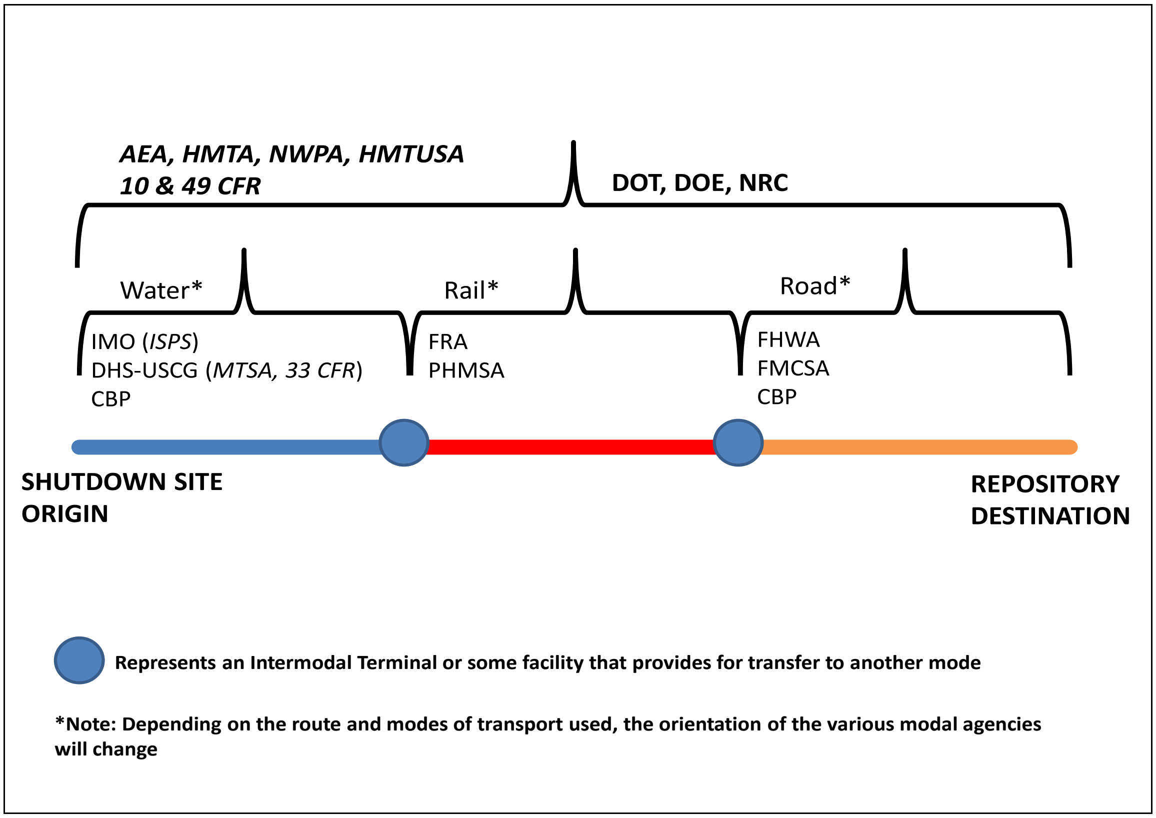

Figure 1. SNF/HLRW Regulatory and Modal Chains

For rail, there are also applicable sections of 49 CFR such as 172.820, 172.822 and Appendix D of Part 172. These regulations specify that routes should be chosen based on the safest or most secure for both a preferred/primary and an alternate route. In general, the routes should minimize storage and delays in transit and should allow for adequate security of materials both in transit and when in a rail yard. Part 172.820 (c) requires that high consequence targets be identified by states, localities and tribes, but also notes that a high consequence target "means a property, natural resource, location, area, or other target designated by the Secretary of Homeland Security that is a viable terrorist target of national significance the attack of which by railroad could result in catastrophic loss of life, significant damage to national security or defense capabilities, or national economic harm." This has been interpreted as covering locations such as water treatment facilities, public water supplies, locks and dams, power generating stations, and pipelines, pipeline transfer locations, and bulk fuel storage terminals. Other important locations are major highway and railroad bridges over major waterways such as the Missouri, Mississippi, Ohio and Columbia rivers.

To provide a comprehensive policy integrating the various 49 CFR components for SNF/HLW shipments, FRA adopted the "Safety Compliance Oversight Plan for Rail

Transportation of High-Level Radioactive Waste and Spent Nuclear Fuel," or SCOP [18][19]. The SCOP provides a mechanism for coordinating regulatory compliance and communication between FRA, the railroads, and other federal, state and local agencies.

In her work on the safety risks involved with transporting SNF/HLW by road, Giglio [6] explains that under HMTA, the FHWA is the primary DOT agency tasked with ensuring safety for the route selected. Under HM-164, the DOT delineated the specific routes that trucks can take when transporting SNF/HLW. As further guidance for highway shipments of SNF, the following criteria were established for highway routing in Part 397.101:

- Minimizing radiological risk
- Accident rates
- Transit time
- Population density and activities
- Time of day

Additional highway routing regulations are provided in 49 CFR 173.22 and 177.825. These regulations identify other factors to be taken into consideration when determining highway routes. These factors include emergency response capabilities, evacuation capabilities, and "special facilities" such as schools, hospitals and stadiums. Under 49 CFR Part 397 subpart D and the administration of the Federal Motor Carrier Administration (FMSCA), the FMSCA, in consultation with state, local, and tribal entities delineate routing protocols for what is described as Highway Route Controlled Quantities (HRCQ). Under Part 397, HRCQ routes outline the quantity that can travel along these specified routes as well as the rules for placarding, notice, and route analysis for highway routing in particular [20]. To support Part 397, specifically paragraph 397.103, the states are required to identify hazardous materials routes that would minimize radiological risk. Construction or other traffic delays are noted as additional factors to take into consideration.

While the primary focus of Giglio's work was on comparing the road option to transporting material via waterborne transport, she explains that dangers associated with transporting by road include sabotage, accident, and exposure to low doses of radiation for those population centers that trucks may pass by [6]. Although she advocates for the use of water based transport to move SNF because of the reduction in populations affected by the transit as well as reduction in security threats, her work was prior to the passage of contemporary maritime security legislation which brings in additional layers of agency involvement and security. The passage of the Maritime Transportation Safety Act (MTSA) [21] adds additional agency involvement, namely the role of DHS through the USCG in ensuring facilities and vessels are in compliance with the statutory language as well as the regulatory requirements of Chapter 33 of the CFR [22].

In contrast to the other modes, water transportation with the passage of the MTSA involves securing both the facility and vessel [22]. This includes the development of Vessel Security Plans, Facility Security Plans and training personnel to ensure safety at these facilities [22]. While ports and other waterfront facilities involved in the transportation of SNF/HLW will be required to comply with the MTSA and its regulatory provisions, one area of uncertainty is whether shutdown sites that will use a water egress point for the SNF will fall under the ambit of the MTSA. To the extent possible, these shutdown sites would need to undergo a facility inspection by USCG under the provisions of 33 CFR 105 *et seq*. to determine whether these shutdown sites are in fact considered MTSA facilities by the USCG. In addition to the MTSA and USCG involvement, when shipments of SNF/HLW are being brought in from international origins, further agency involvement from Customs and Border Protection as well as the International Maritime Organization (IMO) and the International Ship and Port Facility Code (ISPS) are involved as the material has passed through international waters. In the case of the United States, the MTSA is the domestic analog law for ISPS, ensuring that there is continuity in interpretation between ISPS and MTSA.

Figure 1 above, provides an illustration of how these statutes and regulations relate to a conceptualized shipment of SNF. The route illustrates a theoretical move involving the three basic modes of water, rail and road along with the operative laws, statutes, and agencies involved along the route.

Additional Agency Involvement and Jurisdictional Consultation

In addition to the overarching statutory provisions set forth in the AEA, HMTA, HMTUSA, and NWPA, agencies with tangential interests as well as jurisdictional stakeholders such as states, localities, and tribal governments have consultation rights and the rights to exercise their traditional "police powers" under the current statutory framework [4][16]. From the perspective of certain agencies, namely EPA, OSHA, and FEMA, their regulatory oversight is specific to non-nuclear related statutes, such as the National Environmental Policy Act (NEPA) [24], Resource Conservation Recovery Act [25], and the Superfund Amendments and Reauthorization Act [26].

For the agencies such as the EPA, OSHA, and FEMA, their role in the transportation of SNF/HLW is viewed as part of the interagency coordination effort, which can lead to greater "jurisdictional friction," as described by Kassen [3]. Although RCRA and SARA are discussed by Kassen [3] as statutory frameworks which discuss the handling of SNF and its subsequent disposal and notification to those affected communities, primary discussion both in Kassen [3] and Giglio [6] focuses on the NEPA process and the role of NEPA at the Federal and State level for determining routes as well as whether the proposed planning for transporting SNF/HLW is consistent with the procedural guidelines established under Title 40 of the CFR [27]. In her article, Giglio [6] explains that when the City of New York sued US DOT [28] over the routes selected, the District Court determined that DOT requirements under the HMTA did not comport with the statutory provisions of NEPA, the Second Circuit [29] determined that NEPA and subsequent Environmental Impact Statements were not necessary, so long as DOT considered alternative routes.

As both Kassen [3] and Giglio [6] point out, under HMTA, the state, local, and tribal communities must be consulted and the state and local governments retain their "police powers" of protecting health and safety of their citizen when consulted about these routes. Under 49 CFR part 397.201 & 397.203, the states are allowed to request a preemption of route determination to avoid a route going through a particular jurisdiction. Although these police powers and part 397.201 enable discussion between state and federal agencies, the court, in *City of New York v. U.S. Dept. of Transportation* has acknowledged that the federal right preempts the police power, when the state police power is acting in contravention of achieving the federal objective, here, such objective would be transporting SNF/HLW through the jurisdiction. While the Second Circuit reversed the lower court's ruling as to the state's power, Giglio [6] and Kassen [3] acknowledge the need for some form of "enhanced federalism;" a greater coordination between federal, state, and local entities to ensure clear lines of communication and consultation throughout the route selection and transportation process.

Figure 2 provides an illustration of how the legal and regulatory framework interacts with the supply chain as it moves from origin to destination through either a domestic or foreign source. Under the hypothetical domestic source scenario, the SNF or HLW moves from a power plant or shutdown site via some transport mode to a transload site and then to a subsequent repository. At each stage different regulatory bodies have an oversight role for either the radioactive material including packaging, the shipment mode, or the transfer, disposition, and security of the cargo. As a result, the DOE and NRC will be involved in almost every phase of the transportation of SNF and HLW from origin to final disposition, but at various junctures various DOT agencies such as FMCSA, FRA and PHMSA, as well as DHS agencies such as TSA will have some oversight role. Accompanying these direct oversight regulatory bodies, other federal and state agencies such as the EPA, state environmental and hazardous materials regulators, as well as state and local law enforcement and emergency response agencies will have some supporting role.

For foreign sourced materials, the origin involves the foreign radioactive waste regulatory authority, the IAEA, and, assuming all such shipment will be via waterborne shipping, a port authority in a foreign country, and international maritime authorities. When the shipment arrives in US territorial waters, oversight and regulatory authority transfers to the US Coast Guard and subsequently to the various domestic transport agencies and port authorities as the SNF/HLW package is offloaded and staged for shipment to a domestic US location. Once offloaded at a port, the same regulatory and oversight agencies involved in domestic source transport come into effect.

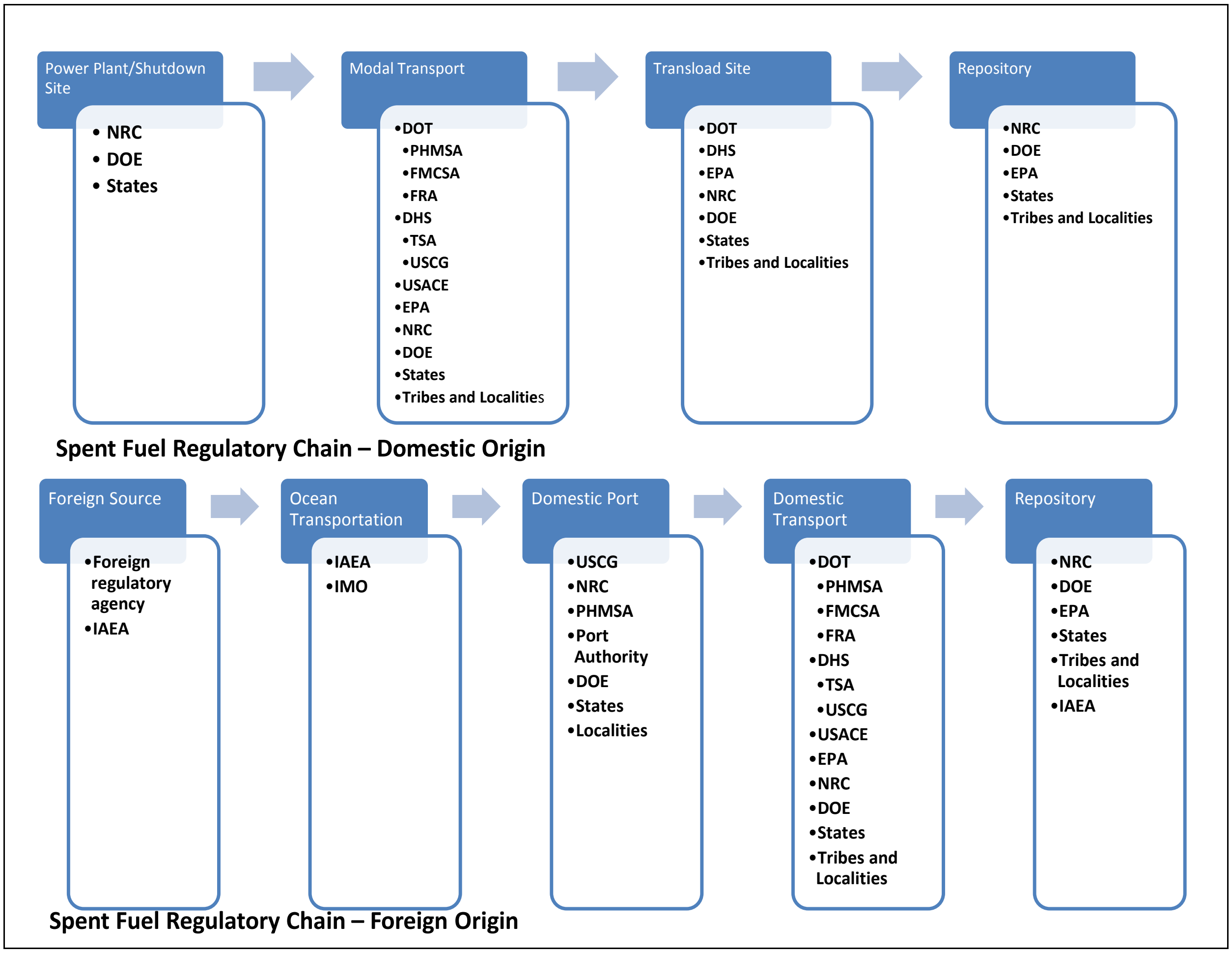

Figure 2. Legal and Regulatory Framework

MAPPING T

Conceptually, the physical supply and logistics chain for SNF/HLW is directly comparable to any other physical transport supply chain, especially if the supply chain has consideration for hazardous materials. This section briefly describes the physical supply and logistics chain for SNF/HLW corresponding to the domestic and foreign sourced scenarios outlined above.

Routing for SNF and HLW follows the legal restrictions outlined below and works from a fairly limited set of origins – US nuclear plants, research reactors, and shutdown sites - and largely theoretical destinations – intermediate storage facilities (ISFSI) or proposed geologic repositories such as Yucca Mountain [1][2]. To accomplish the task of planning and routing SNF in the US, several studies were commissioned to explore the site characteristics of the existing US nuclear plants such as report for the Crystal River facility [30] and the desired characteristics of any geologic repositories such as Yucca [31]. Recently, studies have been completed to revisit the site and transportation connectivity conditions for the several shutdown reactor sites in the US [32]. Based upon these studies a conceptual map of the physical supply chain can be developed as shown in Figure 3.

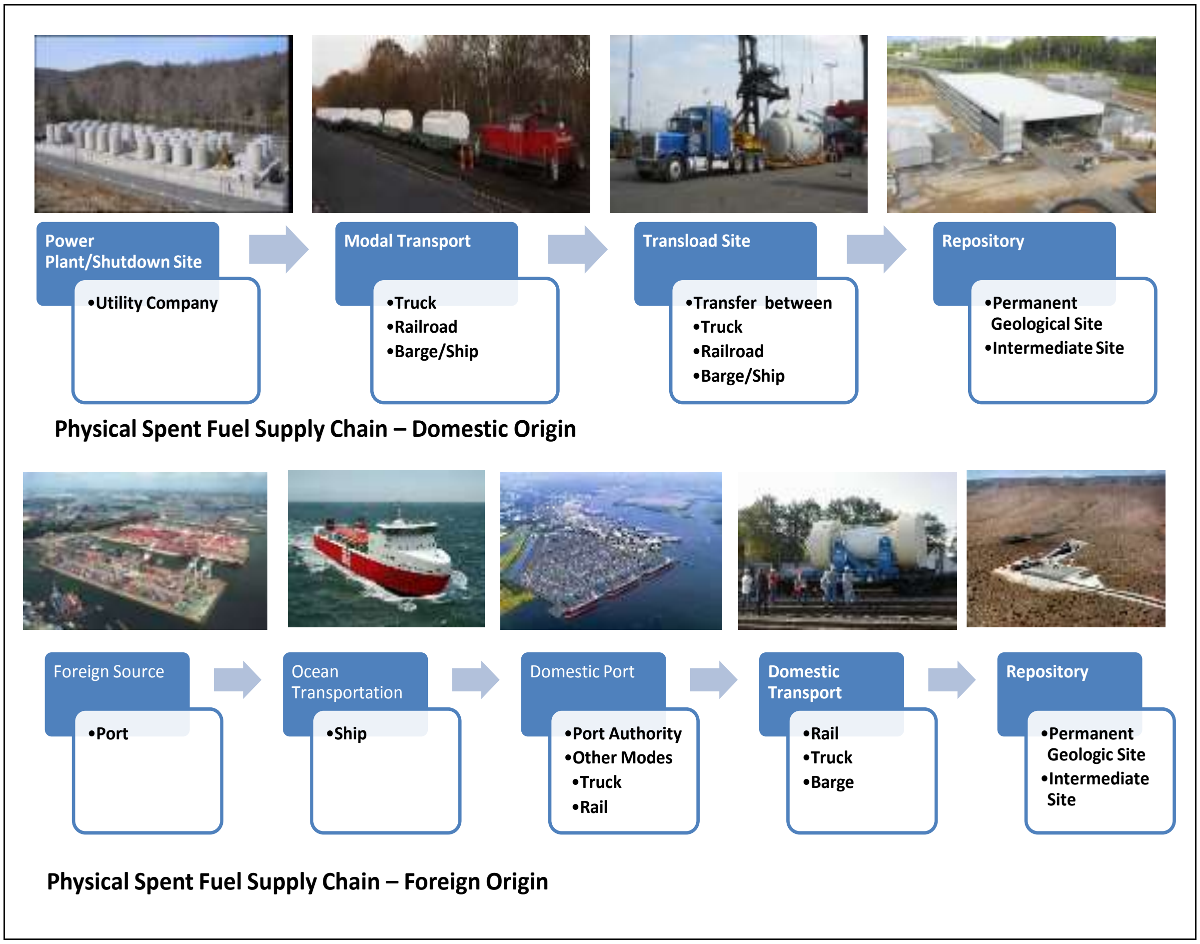

Figure 3. Physical Logistics and Supply Chain for SNF/HLW

This physical logistics and supply chain for SNF follows the same structure as the legal and regulatory chain described above. Domestic shipments have an origin at a nuclear plant, the dry storage cask location at a shutdown facility, or at a research reactor, proceed to be transported by one or more modes, which may involve the transfer between modes at a transload site, where SNF transportation casks would be transferred between modes, i.e. truck-to-rail, or rail-to-barge for example. The shipment will then proceed to the disposition destination for storage in either an ISFSI or permanent geologic repository.

For foreign origin shipments, the point of origin would be a foreign port which would then move via ship to a domestic US port for offloading. At the port, the shipment might be transferred directly to rail, a smaller waterborne commercial shipper, or a truck for subsequent transfer. One or more of these modes would then combine to complete the shipment to the designated storage location.

In addition to the site characteristic studies, DOE commissioned a series of route planning models that eventually came to form the current WebTRAGIS routing platform [33]. WebTRAGIS is a multi-modal routing geographic information system comprised of three modal networks: highway, railway and waterway. For each of these networks key features for the transportation of SNF and HLW are incorporated such as the locations of all nuclear plants, research reactors, and shutdown sites in the United States, the designated HRCQ routes for the national highway system, and the various ports on both the coasts and inland waterways. As a result, highly accurate routes can be generated by route planners to examine various route solutions and scenarios for routing SNF and HLW in the United States.

Representative Scenario Routes

In order to illustrate the complexities of the interactions between the physical supply chain and the legal/regulatory chain for SNF, several representative routes were generated in WebTRAGIS. Two of the routes originate at the recently shutdown Crystal River power plant in Florida with one being via highway and the other via rail. The shipments have a terminating location set as DOE's Savannah River Site (SRS)[1]. The third route is a foreign origin shipment entering the US at Charleston, SC and traveling to the Joint Weapons Station in North Charleston. From this location, the shipment could then move via highway, railway or inland waterway to a final destination for storage.

Crystal River presents a unique situation in that the site has direct rail access. As a result, rail shipments of SNF can be made without recourse to a transload operation to complete the move. This is not the case at many of the nuclear plants and shutdown reactor sites in the US, however. For many of these facilities, a heavy-haul truck will be needed to move the SNF casks to a transload location where the cask could be transferred to rail or to barge.

Figure 4 provides a highway route from Crystal River to SRS. Under this scenario the entire shipment is made via heavy-haul truck. The route conforms to the applicable federal routing guidelines established under the operative federal code, while also following the designated HRCQ routes established by Florida, Georgia and South Carolina. As such, the route is not necessarily the most direct or shortest route, but it is the shortest and most direct route available under the regulatory conditions. Not only DOE and NRC are involved, but also the FMCSA, and the applicable state agencies responsible for oversight, monitoring and security of hazardous materials shipments.

[1] It should be noted that the selection of Savannah River is done strictly for illustrative purposes and in no way represents or implies an official endorsement of the route destination by the US Department of Energy.

Figure 4. HRCQ Highway Route

The rail option for shipping SNF from Crystal River is illustrated in Figure 5. This route is more direct and shorter than the highway route due to the absence of HRCQ regulations for shipments made by rail. However, the rail shipment is subject to a consideration that does not affect highway shipments: the involvement of more than one railroad and the need to transfer custody between one or more railroad companies. For example, the railroad servicing the Crystal River plant is the Florida Northern. Florida Northern would pick up a railcar carrying a SNF cask and then proceed to interchange with CSX railroad at Newberry, Florida. CSX would then transport the cask on their network to an interchange point right outside the SRS facility to interchange with the local, on-site SRS switching railroad. The SRS railroad would then deliver the cask to a disposition location on the SRS site for storage. For this route the regulatory agencies involved would be the DOE and NRC as well as FRA from start to finish. PHMSA and TSA would be interested, but ancillary, agencies. Due to the legal nature of rail shipments, state involvement and oversight would be minimal.

Figure 5. Railroad Route

Finally, Figure 6 provides an example of a foreign origin shipment entering the United States. In this case, the shipment travels through international waters, enters into US territorial waters and the approaches Charleston, South Carolina. At Charleston, the shipments travels through the port and then up the Cooper River to the Joint Weapons Station in North Charleston. Under this scenario, the shipment moves from international oversight at the transition point to US territorial waters, where the USCG maintains primary oversight until offloading at North Charleston. At the time of physical custody transfer, the legal oversight shifts from the Coast Guard to NRC, DOE and the agencies responsible for the final mode(s) of transport.

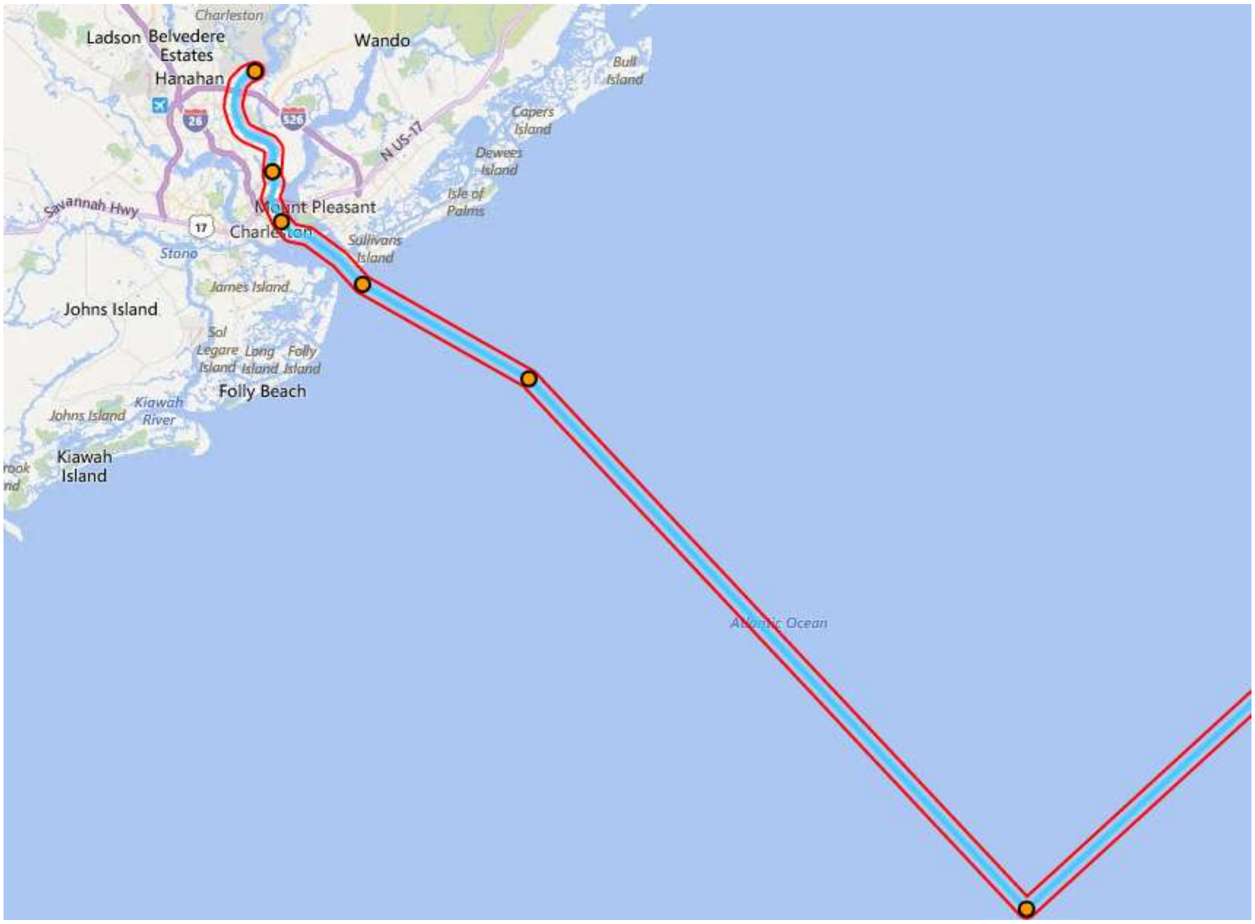

Figure 6. Ocean Route to Port

PHYSICAL SUPPLY CHAINS AND LEGAL CHAINS IN TANDEM

As can be inferred from the preceding sections, the transportation of SNF and HLW in the US represents a complex and closely coupled system of physical custody and corresponding regulatory oversight. In the spatial dimension, SNF physically shifts from origin to destination via a variety of possible modes and combinations thereof. As these movements occur across the physical landscape, corollary movements are made within the legal landscape. This corresponding coupling of the physical and legal landscapes is illustrated in Figure 7.

Perhaps the most salient feature of domestically originating SNF/HLW shipments is the regulatory tandem presence of the NRC and DOE from point of origin to subsequent destination along with the legal framework established by NWPA and HMTA. If shipments follow the stated DOE preference to move by rail, this agency tandem will be accompanied for a considerable portion by the FRA and the applicable sections of 49 CFR such as Part 172 and HM-164. Even for shipments originating on trucks, or even water, they are likely to be transferred to rail at the earliest available opportunity[2] such that agencies such as FMCSA, TSA, or states and localities, are likely to have only minimal oversight. Regarding ocean-borne foreign sourced material, the regulatory oversight is slightly more problematic as the exact point of regulatory oversight from the USCG to NRC, DOE and a USDOT agency, is somewhat nebulous. Of even more uncertain provenance are the regulatory oversight roles of agencies such as the EPA or the US Army Corps of Engineers (for the use of inland waterways) under the auspices of NEPA.

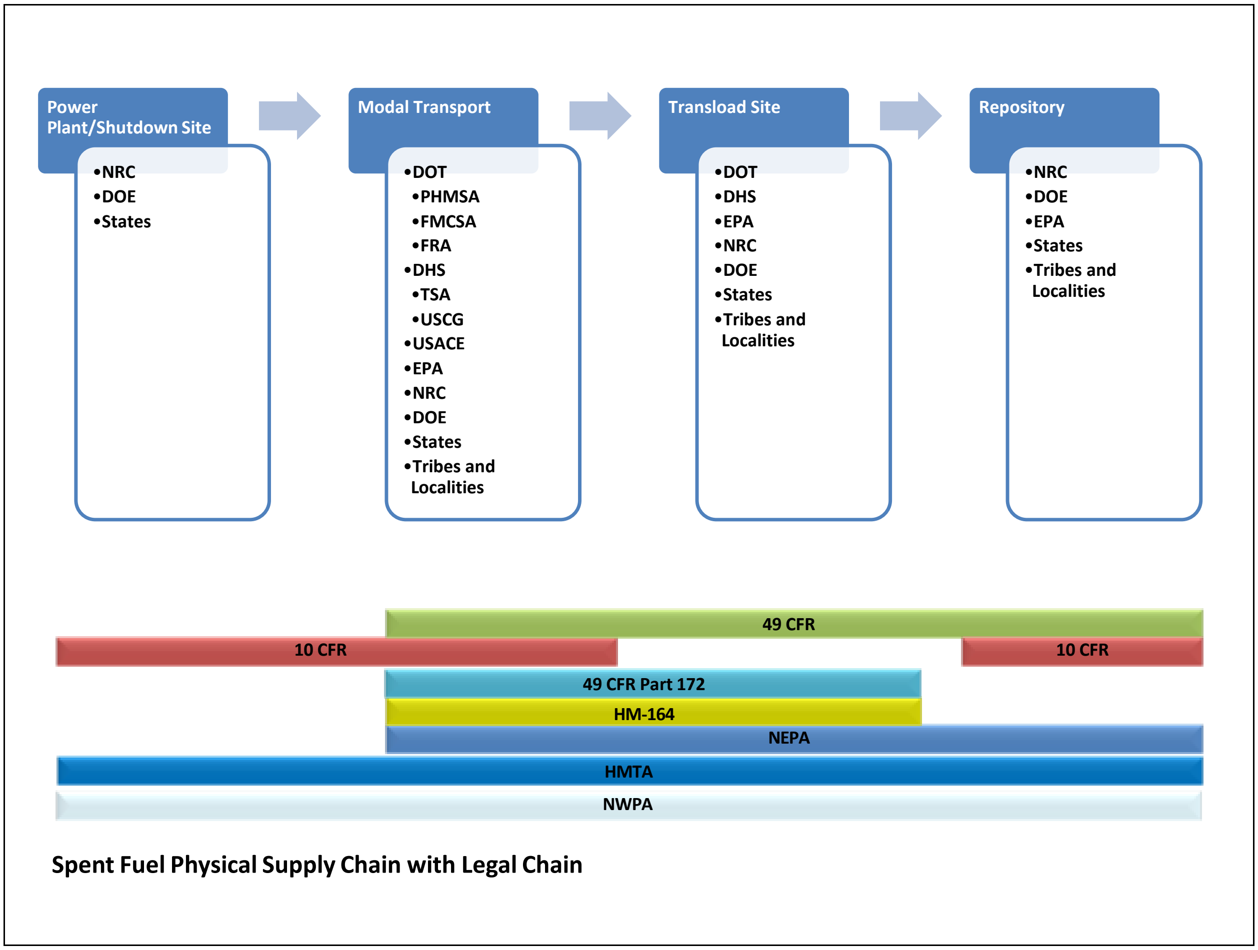

Figure 7. Spent Fuel Physical and Legal Chain

RESILIENCE AND CHALLENGES TO RESILIENCE IN SNF/HLW ROUTING

Whether discussing the legal domains, the physical routes, or the physical possession of the SNF/HLW while in transit, there exists an element of resilience, be it in the redundancy of the various routes that can be generated through consultation and regulatory control, the overlapping jurisdictions, and the ability for multi-level governance in the process. While we discuss how the process of

[2] At present, DOE has not delineated the necessary site requirements and capabilities for transferring spent fuel casks between modes. As a result, any transfer points identified in this paper, or any other work, are purely speculative and made only under conditions of what is deemed to be the best available information.

transporting SNF/HLW can be resilient, what exactly does resilience mean in this context, or in the greater context of freight transportation?

Recent work in defining freight transportation traces the concept of "resilience" for freight back to general supply chain resilience. As explained by Ta, Goodchild, and Pitera [33], the definition of freight transport resilience stems from the work of Yossi Sheffi, specifically, his book*, The Resilient Enterprise: Overcoming Vulnerability for Competitive Advantage* [35]. Sheffi examines the strength of supply chain resilience from the perspective of people, processes, and technology as drivers to develop flexibility as well as strategies and measures to mitigate disruptive actions [35]. With this working understanding of resilience, Ta *et al* define freight resilience in terms of the behavior of the physical infrastructure, the users, and the managers of the infrastructure. This is further supported by work of Faturechi and Miller-Hooks [34][36] who define the resilience of freight systems by features such as redundancy, robustness, flexibility, survivability. Table I lists the various performance measures associated with resilience and transportation systems, particularly in the context of freight.

Table I. Common Performance Measures and Definitions of Resilience. Source: Faturechi and Miller Hooks [35]

Measure	General Definition
Risk	Combination of probability of an event and its consequences in terms of system performance
Vulnerability	Susceptibility of the system to threats and incidents causing operational degradation
Reliability	Probability that a system remains operative at a satisfactory level post disaster
Robustness	Ability to withstand or absorb disturbances and remain intact when exposed to disruption
Flexibility	Ability to adapt and adjust to changes through contingency planning in the aftermath of disruptions
Survivability	Ability to withstand sudden disturbances to functionality while meeting original demand
Resilience	Ability resist, absorb, and adapt to disruptions and return to normal functionality

While Faturechi and Miller-Hooks define attributes of resilient freight systems, the definition advanced by Ta *et al* [34] implies that the physical infrastructure is not the only consideration; rather the physical infrastructure is an element, affected by use, management, and policy/legal frameworks.

In the context of SNF/HLW routing and regulatory oversight, we see elements of robustness and redundancy in the multiple agencies involved in the process as well as the various route options that can be generated depending on the various criteria established under the regulatory regimes in place as well as the preferences of those agencies and operators engaged in transporting the material through the system. For example, use of tools such as WebTRAGIS provide decision-makers with the ability to generate routes with various modes, taking into account HRCQ regulations as established under 49 CFR 397, the various rail companies potentially involved in the route, and provide notice to those jurisdictions, agencies, and communities with potential transit through their domains. Given this flexibility and a robust platform that can account for jurisdictional, modal, and supply chain considerations, a strong argument can be made that the pieces are there to develop a resilient supply chain for SNF transport, from a legal/regulatory perspective as well as a physical route/physical supply perspective.

On the other hand, one of the institutional challenges faced by transportation, not just SNF transport is the overlapping jurisdictional nature of transport. As previously mentioned, given the myriad of interests, both federal, state, local, tribal, as well as the modal agencies and DOE interests at play, there is room for conflict and inter-agency coordination challenges. As Kassen [3] points out, this conflict has already taken place, especially in the context of the secondary statutes and agencies such as EPA, OSHA, and FEMA. To this end, regulatory strategies for coordination can be developed such as regulatory shared space, a concept advocated by Freeman and Rossi [37]. Shared regulatory space, as proposed by Freeman and Rossi advocates the notion that those agencies occupying a similar policy space can coordinate rulemaking and oversight through joint-rulemaking and review. Using their example of emissions standards and the EPA and National Highway Transportation Safety Administration (NHTSA), Freeman and Rossi argue that such coordination can clarify rules and streamline regulatory conflicts. Applying this to SNF/HLW transport, a similar regulatory space can be established to allow for consultation, coordination, and oversight to ensure complete stakeholder engagement and regulatory controls [37].

CONCLUSION

The movement of SNF/HLW presents unique physical and regulatory challenges for those shippers, agencies, and stakeholders involved in the endeavor. In this paper, we attempt to outline the various legal, physical, and supply chain aspects and create a framework and visualization approach to encourage discourse and discussion. Through mapping the legal, physical, and supply chain levels of transporting SNF/HLW materials, decision makers and those interested stakeholders can clearly view their involvement in the process and develop strategies and policy spaces to facilitate inter-agency, multijurisdictional, and multi-stakeholder engagement with clear understanding of the physical and regulatory controls in place.

REFERENCES

1. Department of Energy. (2004) *Record of Decision on Mode of Transportation and Nevada Rail Corridor for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada.* Federal Register 69:18565-18569. April 8.
2. Transportation Research Board and National Research Council. *Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level*

Radioactive Waste in the United States. Washington, DC: The National Academies Press, (2006).
3. M. KASSEN, *Interagency Conflicts in the Regulation of Hazardous Materials in Transport: The Nuclear Materials Example*, pp. 47-61. Chapter within *Transportation of Hazardous Materials*, L. MOSES & D. LINDSTROM, Kluwer Academic Publishers, Norwell, Massachusetts, 1993.
4. Hazardous Material Transportation Control Act of 1975, 49 U.S.C § 5101 *et seq*. (1975)
5. Nuclear Waste Policy Act of 1982, 42 U.S.C. § 10101 *et seq.* (1982)
6. S.B. GIGLIO, "Transportation of Spent Nuclear Fuel: The Need for a Flexible Regulatory System," *Boston College Environmental Affairs Law Review*, 12, 51 (1985).
7. Carriage by Rail, 49 CFR § 174.
8. Carriage by Aircraft, 49 CFR § 175.
9. Carriage by Vessel, 49 CFR § 176.
10. Carriage by Public Highway, 49 CFR § 177.
11. Atomic Energy Act of 1954, 42 U.S.C. § 2011 *et seq*.
12. NRC & DOT, MOU Between the NRC and DOT(Fed. Register 1979) [hereinafter 44 FR 38690].
13. "Summary of the Nuclear Waste Policy Act," United States Environmental Protection Agency, http://www2.epa.gov/laws-regulations/summary-nuclear-waste-policy-act, Last visited October 22, 2015.
14. Requirements for physical protection of irradiated reactor fuel in transit. 10 CFR § 73.37.
15. "Transporting Hazardous Materials," Department of Labor, https://www.osha.gov/SLTC/trucking_industry/transportinghazardousmaterials.html, Last visited October 22, 2015.
16. J.A.D. SMITH and J.B. REED, *Spent Fuel Transportation: History, Status and State Involvement.* Washington, DC: National Conference of State Legislatures, 2004.
17. Hazardous Material Transportation Uniform Safety Act, 49 U.S.C § 5101 *et seq*. (1990).
18. "Ted Willke, Associate Administrator for Hazardous Materials Safety, Pipeline and Hazardous Materials Safety Administration, and Edward Pritchard, Director, Office of Safety Assurance and Compliance, Federal Railroad Administration, U.S. Department of Transportation before the Committee on Commerce, Science, and Transportation United States Senate," September 24, 2008, http://testimony.ost.dot.gov/test/pasttest/08test/willike1.htm, Last visited October 22, 2015.
19. Federal Railroad Administration. (2005) *Use of Dedicated Trains for Transportation of High-Level Radioactive Waste and Spent Nuclear Fuel.* Report to Congress. March.
20. National Hazardous Materials Route Registry, 80 Fed. Reg. 82, 23860 (April 29, 2015) (to be codified at 49 C.F.R. pt. 397).
21. Maritime Transportation Security Act of 2002, 46 USC § 70101 *et seq.* (2002).
22. Maritime Security provisions can be found in 33 CFR 104 & 105.

23. P. OLEKSZYK, *Analyzing Routes for the Transportation of Hazardous Materials Including Radioactive Waste and Spent Nuclear Fuel by Use of Effective Risk Estimation*, pp. 77-84. Chapter within *Transportation of Hazardous Materials*, L. MOSES & D. LINDSTROM, Kluwer Academic Publishers, Norwell, Massachusetts, 1993
24. National Environmental Policy Act of 1969, 42 U.S.C § 4321 *et seq*. (1969).
25. Resource Conservation and Recovery Act of 1976, 42 U.S.C. § 6901 *et seq*. (1976)
26. Superfund Amendments and Reauthorization Act , 42 U.S.C. § 9601 *et seq*. (1986)
27. CEQ Regulations for Implementing NEPA, 40 CFR § 1500 *et seq.* (1969)
28. *City of New York v. U.S. Dept. of Transportation*, 539 F. Supp. 1237 (S.D.N.Y. 1982).
29. *City of New York v. U.S. Dept. of Transportation*, 715 F.2d 732 (2d Cir. 1983).
30. E. BRADLEY and A.P. GEIST, "Near-Site Transportation Infrastructure Project Draft Report and Assessment: Crystal River Power Plant, (Florida Power Corporation), Citrus County, Florida," Nuclear Assurance Corporation, NAC Report No. C-89108K (1989).
31. Department of Energy. (2002) "Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada." Department of Energy Office of Civilian Radioactive Waste Management, DOE/EIS-0250.
32. S.J. MAHERAS, R.E. BEST, S.B. ROSS, K.A. BUXTON, J.L. ENGLAND and P.E. MCCONNELL, "Preliminary Evaluation of Removing Used Nuclear Fuel from Shutdown Sites," Department of Energy, FCRD-NFST-2013-000238, (2013).
33. WebTRAGIS Version 5.0. Oak Ridge National Laboratory.
34. C. TA, A. GOODCHILD and K. PITERA, "Structuring a Definition of Resilience for the Freight Transportation System," *Transportation Research Record,* 2097, 19 (2009).
35. Y. SHEFFI. *The Resilient Enterprise: Overcoming Vulnerability for Competitive Advantage.* The MIT Press*,* Cambridge, MA (2005).
36. R. FATURECHI and E. MILLER-HOOKS, "Measuring the Performance of Transportation Infrastructure Systems in Disasters: A Comprehensive Review," *Journal of Infrastructure Systems,* 21, 1 (2015).
37. J. FREEMAN and J. ROSSI, "Agency Coordination in Shared Regulatory Space," *Harvard Law Review*, 125 (2012).

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