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SOCIOTECHNICAL SYSTEMS DESIGN FOR CONSENT-BASED SITING OF NUCLEAR WASTE FACILITIES

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Abstract

Successfully executed radioactive waste management projects are critical to the sustainability of the nuclear industry. While there's a tendency to think the challenges to successfully siting radioactive waste management facilities are technical, public acceptance is perhaps the biggest challenge. The social aspects of nuclear waste storage, transportation and disposal cannot be understated; hence the growing emphasis on consent-based siting. While there are examples of successful and unsuccessful siting efforts there is no single "roadmap" or "framework" to describe how to secure community consent. One such potential roadmap or framework could be Sociotechnical Systems Design. Sociotechnical Systems Design recognizes the interaction between people and technology and considers both social and technical factors that influence the functionality, practicability, acceptability, and usage of a system. A holistic analysis of any system considers five work system elements (people, technology/tools, tasks, policies/organization, and the environment) and identifies where requirements or conditions of these elements have consequences triggering changes on the others. Concurrent Engineering is a systematic approach that enables designers to consider all system elements and their interfaces throughout the lifecycle by incorporating stakeholders early in the pre-design stages. The paper describes how to use a sociotechnical system that relies on a Concurrent Engineering process to achieve consent-based siting of a nuclear waste management facility. The resulting framework addresses the socio-economic requirements of communities while facilitating communication and interaction opportunities between technical, political, and social stakeholders. This will allow communities to access information and raise concerns about nuclear waste management locally, while letting technical specialists factor these concerns into the waste management facility design, providing information where needed, and reducing the need for rework and retrofitting. Staged implementation of sociotechnical systems design supported by concurrent engineering can be key to consent-based siting and a successful nuclear waste management program.

1. PROBLEM STATEMENT AND OVERVIEW

The challenge to addressing nuclear waste management is identifying a facility site. Within the United States this is complicated further by current law that prevents pursuing a government owned consolidated interim storage facility until a permanent repository receives a license. [1] The creation of a consolidated interim storage facility is controversial as waste would be transported twice in the process of getting to a permanent geologic repository. It could be argued that the current process of storing spent nuclear fuel onsite at the commercial nuclear power plant where it was generated eliminates the need for consolidated interim storage. [2] The other argument is "a centralised store would offer cost and efficiency benefits – especially for the Department of Energy, which has to reimburse utilities for the full cost of the temporary storage." [3] Both consolidated interim storage and long-term geologic repository facilities must be safe, technically sound, and address transportation considerations. The most important factor is the host community as it must become an advocate of the facility: more than just willing; the community must be committed. Only a committed community will be able to sustain the effort of gaining approval from the Nuclear Regulatory Commission (NRC), the US Department of Energy (DOE), the community's state government, the neighbouring communities, and so on. The list of social stakeholders for a nuclear waste facility could be potentially very long.

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A potential first step to solve America's nuclear waste problem is to develop a consent-based siting approach to site a nuclear waste management facility, whether it be consolidated interim storage or a geologic repository. Consent-based siting cannot stop at the host community level. It must, at a minimum, pursue the agreement of state government, federal government, and communities potentially impacted by the transportation of the nuclear waste. Site selection for spent nuclear fuel has historically been technology-driven but has failed to secure consent among all the levels of stakeholders. The theory described below introduces a potential framework for science-led, consent-based siting.

2. SOCIOTECHNICAL SYSTEMS AND CONCURRENT ENGINEERING – BACKGROUND

Sociotechnical Systems (STS) is a theory of work systems design that recognizes the interaction and dependencies between people and technology. "The concept… is derived from the premise that any production system requires both a technology, a process of transforming raw materials into output, and a social structure linking the human operators both with the technology and to each other." [6] As such, STS theory aims to achieve joint optimization of the social and technical aspects of the system within the environment in which the system performs. "Joint optimization" suggests that social and technical subsystems can be balanced to optimize the outcome of the system. [7] Sociotechnical systems recognize there is an external subsystem, the environment (including the political influences), moderating the balance between social and technical system requirements.

Sociotechnical systems are defined by boundaries and can range from job-specific work systems to fully integrated communities. Community Ergonomics asserts that people perform differently if work system designers "plan new community systems which consider the purpose, motivations, interest, and characteristics of residents." [8] Community Ergonomics aims to "improve human interactions, evolution, law, and planning for positive organization to support self-regulation and control of community resources." [8] This is relevant for consent-based siting for nuclear waste management, identifying locations and planning infrastructure to ensure compatibility with the host community goals, capabilities, and expectations while allowing communities to actively manage their role in the siting process.

The Balance Theory [9], taken from the industrial engineering field of human factors, identifies 5 system elements to any work system. These elements are the people, the technology and/or tools, the tasks, the policies and organization, and the environment. The theory was originally developed to conceptualize the loads that working conditions can exert on worker stress and was used to develop strategies for stress reduction. Since then, the theory has become a generalized tool in the human factors field, providing a way to visualize the interfaces of any work system and identify opportunities for managing system changes. A revisit of the theory [10] twenty years from its first publication highlights four emerging areas of application of the Balance Theory: (a) multilevel analysis of the work system, (b) understanding the non-work sphere, (c) impact of the work system on worker performance, and (d) application to health care and patient safety. Application to consent-based siting for nuclear waste management falls within the first two emerging areas.

Balance Theory posits that every work system is formed by 5 core elements and a change in any of the elements will affect the others. The five elements of the work system essentially define a sociotechnical system:

- **Tools and technologies that define the technical subsystem.** The "technology" refers to all the tools and technologies (both micro and macro) needed to complete each of the tasks required by the system, including the degree of automation and reliability in the technology, the tools that an operator would need to perform the task, and the availability, complexity, performance, and maintenance through the lifecycle.
- **Tasks and activities (work) generated in the technical subsystem.** The "task" element defines any activities or operations generating work through the system.
- **People that act and interact with the system.** The "people" element considers all community personas, demographics, values, personnel and staffing needs, and their intrinsic characteristics.
- **Organizations and norms that define and control the social subsystem and its interactions with the technical subsystem**. The "organization" details the policies and procedures that regulate the system, whether directly or indirectly, including organizational structure, communication pathways, and any procedures: escalation, maintenance, emergency response, etc. and

- **The complex environment within which the system operates.** The "environment", an external subsystem, describes the environmental variables within which the work system operates. These variables are normally defined for physical climatology and geographical environments, but can also relate to the economic, social, and political environments that affect the system (i.e. the STS external subsystem).

Balance Theory advocates for the assessment of changes in any system element, which allows designers to identify the consequent changes on other elements and generate adjustments or propose solutions to balance and mitigate adverse effects. Those adjustments and solutions can be identified from any of the 5 system elements to support the stability of the system. Figure 1 illustrates the 5 elements of the Balance Theory within the STS framework.

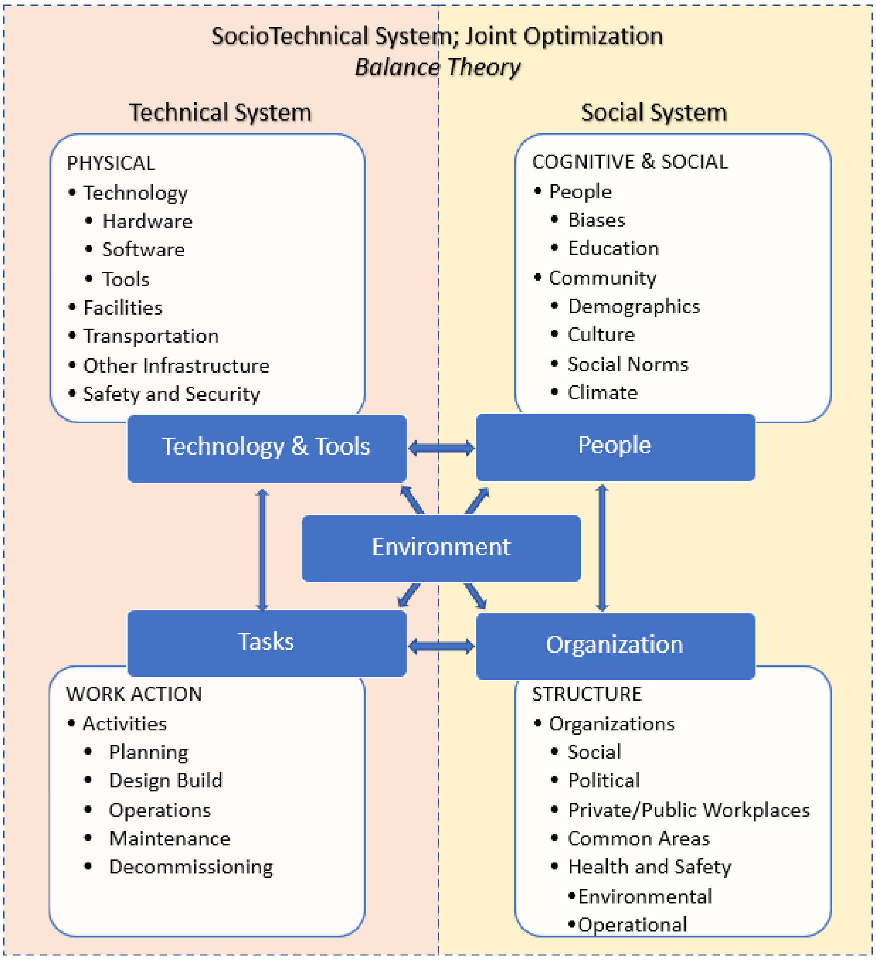

Figure 1: STS Balance Theory model for conceptualizing the elements of a work system, where each element interfaces with other elements.

Concurrent Engineering (CE) is a non-linear, systematic approach to product and process design that requires the input and contribution of representatives from all system stakeholders early in the requirements gathering stages and through the design process. It is intended to cause the developers to consider all elements of the product lifecycle from the outset, from conception to disposal. [11] While design changes can be applied at any time, they are easiest and less expensive to implement in the earliest stages of development. Concurrent Engineering aims to address this by including representatives from the entire product lifecycle during the early stages of requirements definition. Since CE was originally envisioned for short lifecycle products, it provided limited consideration for operation and continued maintenance of the final product. However, these factors, along with decommissioning of the system, must be considered in the lifecycle analysis for nuclear waste management. **Error! Reference source not found.** summarizes four guidelines common to CE models and provides the starting point for the application of STS and CE to support consent-based siting for nuclear waste management [12].

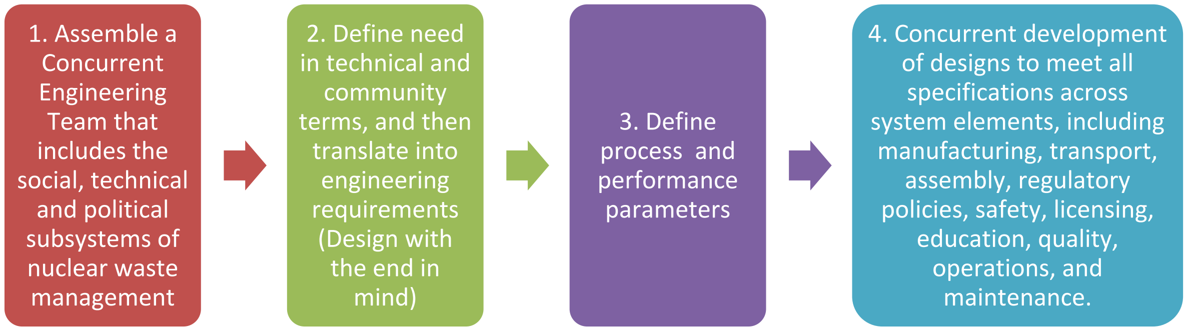

Figure 2: Concurrent Engineering Guidelines applied to Nuclear Waste Management.

3. A SOCIOTECHNICAL SYSTEMS DESIGN FRAMEWORK FOR NUCLEAR WASTE MANAGEMENT

Applying STS and CE principles to nuclear waste management provides a "roadmap" or "framework" to pursue community consent for siting of nuclear waste facilities. STS supports the design process from both the technology and the community standpoint, enabling communication channels and creating opportunities to integrate community and technical needs into the decision-making process on both ends. **Error! Reference source not found.** introduces the Concurrent Engineering and Sociotechnical System Design Framework for Nuclear Waste Management.

3.1. Problem Definition Stage

The problem definition stage outlines the need for a nuclear waste management facility with pre-defined technical characteristics. It should include a description of the need and minimum criteria for success, with host community, state, and federal consent and support being part of such criteria. It should also include an overview of external influences that may interface and moderate potential solutions.

The problem definition also outlines the siting alternatives and stakeholder definition for each site. The multi-functional team advocated by concurrent engineering principles calls for collaborative partners that work together towards a shared outcome. To the extent possible, the membership of that team should be identified at this stage, developing a comprehensive communication plan for the site that includes all stakeholders at different levels. A RACI chart (Responsible, Accountable, Consulted, Informed) could be used to define the roles and responsibilities of the stakeholders. [13] CE team members are representatives from stakeholder groups. Ultimately, the CE team must have the ability to successfully address the inherent uncertainties and to represent a broad range of professional skills, including engineering, science, manufacturing, operations, emergency preparedness, industry regulations, policy, marketing, and communications. A CE team must be identified for each host site candidate.

In general, for a nuclear waste management effort, the CE team membership must be defined early in the problem definition based on needs and relevant factors of the various host communities. The CE team membership could include representatives from DOE, nuclear power generators, unions, policy makers, transportation, facility designers, builders, managers, manufacturers and suppliers, operations, and stakeholder representatives from the host community among many others. This team will partner in designing a facility that meets technical needs, and a social system that addresses community concerns, to achieve consent while defining goals and priorities for successful lasting operations.

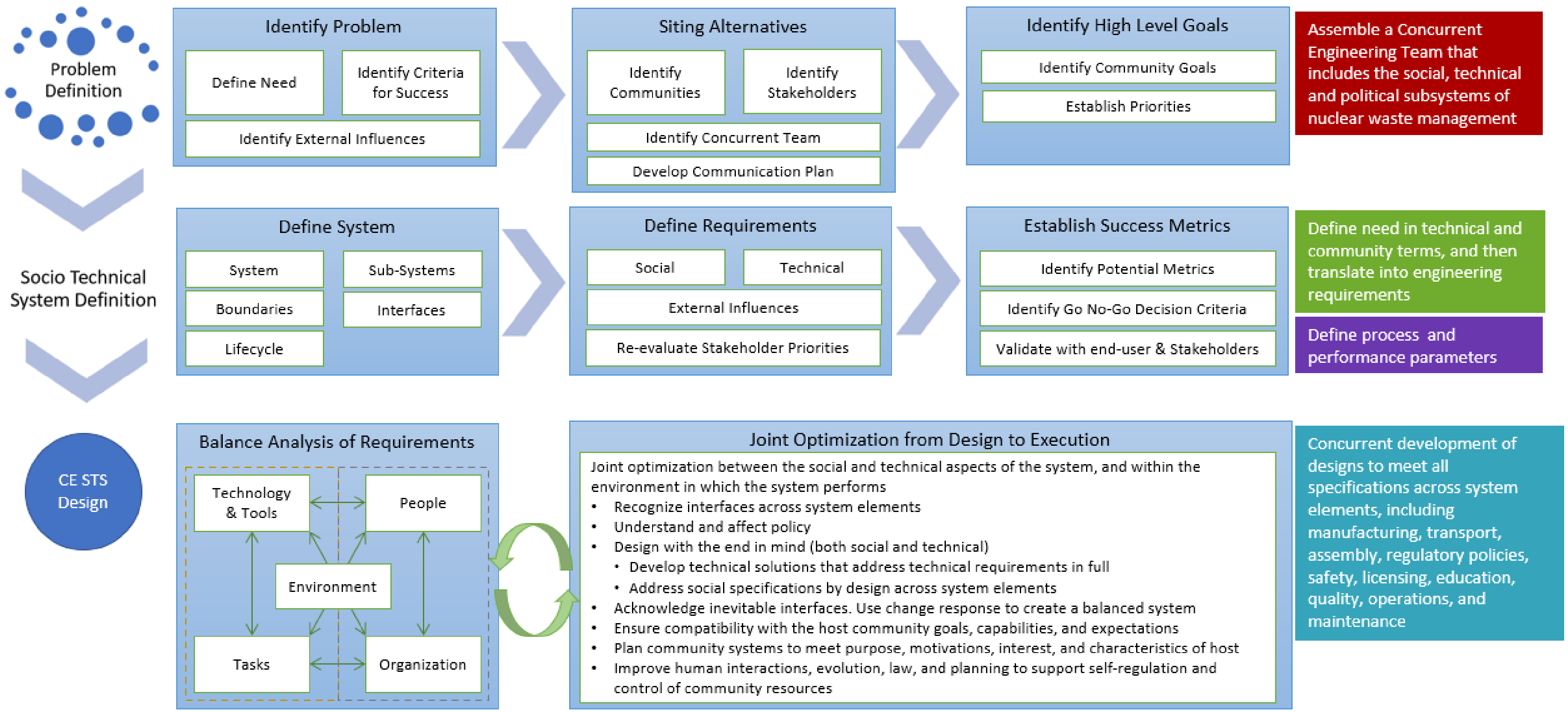

Figure 3: Concurrent Engineering and Sociotechnical System Framework for Nuclear Waste Management Consent-Based Siting.

3.2. Sociotechnical System Definition Stage

The STS definition stage defines the system and sub-systems, both technical and social, including the boundaries and interfaces between them. This stage clearly identifies the functional and technical requirements of the system. Requirements include:

- Social – to be identified and defined by stakeholders, weighted, and discussed within the CE team
- Technical - expected lifecycle of the facility, description of the waste, logistics and operations (such as transportation, storage, and disposal) and decommissioning at the end of the facility life-term
- External influences - In a consent-based siting process, policy is a critical subsystem moderating the social and technical subsystems

Error! Reference source not found. illustrates the key questions that guide subsystem definition for a nuclear waste management STS. Addressing these questions will define key requirements of each subsystem. This stage also requires making decisions regarding decision factors, metrics, and tools that will be used to evaluate performance parameters and facility success.

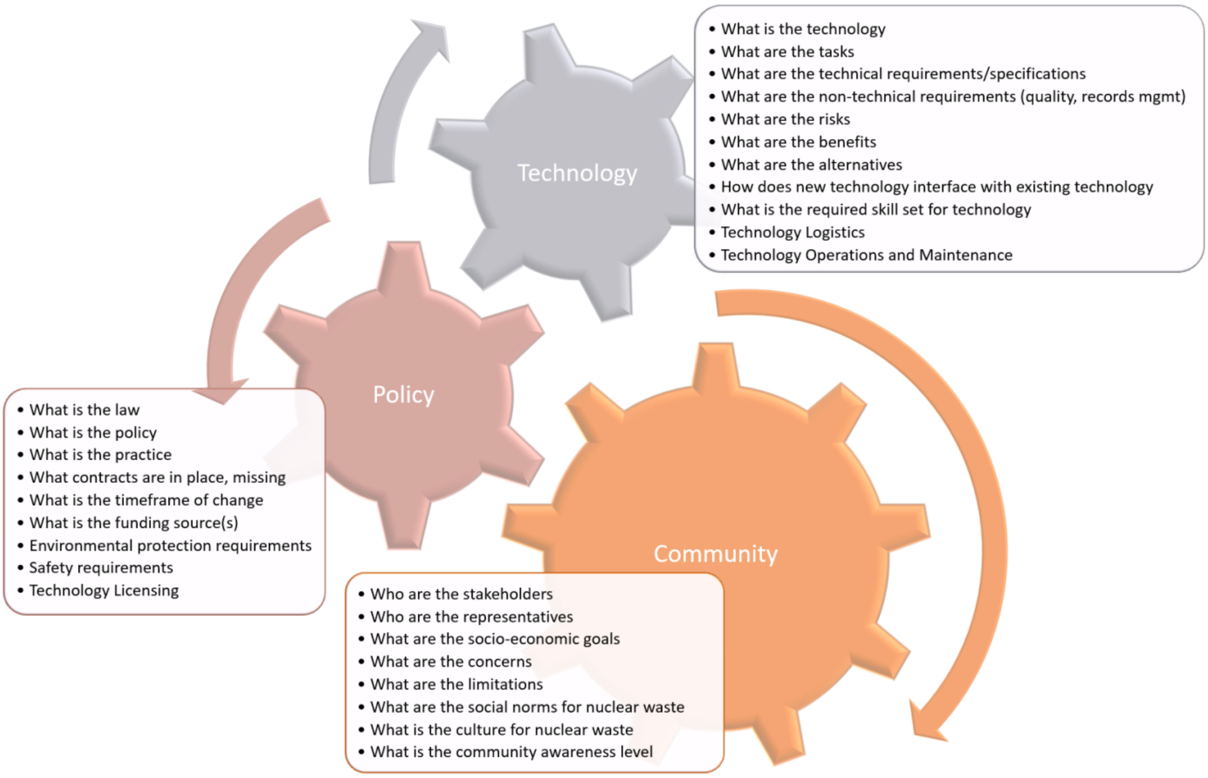

Figure 4: Key questions to support STS system definition of a nuclear waste management facility.

3.3. Concurrent Engineering and Sociotechnical System Design Stage

The CE STS design stage is an iterative process. Both the social (community, people) and technical (technology, tasks) systems are examined, including the interfaces between them in contemplation of the environment, to generate a baseline analysis of the current state of the community and the changes the new nuclear waste management facility would bring. A technical design will evaluate social concerns that may be addressed in the design of the facility. A social analysis will ensure that the community is enabled to provide the infrastructure and support needed for successful technology operations. The interfaces between the five elements are managed to ensure congruency and balance.

Joint optimization considers the impact the holistic system, including the community, economics, environmental impact, job market and education requirements, etc. A transition impact analysis may be needed to support the transition while the facility is being built. A few principles to follow during joint optimization of a nuclear waste management facility, its community, and the environment include:

- Recognize interfaces across system elements
- Understand policy and build in time for change (if needed)
- Design with the end in mind (both social and technical)
    - Develop technical solutions that address technical requirements in full
    - Address social specifications by design across system elements
- Acknowledge inevitable interfaces. Use change response to create a balanced system
- Ensure compatibility with the host community goals, capabilities, and expectations
- Plan community systems to meet purpose, motivations, interest, and characteristics of host
- Improve human interactions, evolution, law, and planning to support self-regulation and control of community resources

4. CONCLUSIONS

The science and engineering communities have traditionally led nuclear waste storage facility siting efforts. This is likely to continue due to the obvious technical needs associated with storage of nuclear waste regardless of the nature of the facility: interim storage, permanent disposal repository, etc. However, STS recognizes that the facility cannot be sited and operated in a vacuum, and the social component needs to be addressed at the micro (i.e. facility workers), meso (i.e. host community), and macro (i.e. regional and state-level stakeholders) levels. CE provides an early opportunity to communicate and clarify expectations regarding the type of support the facility would require from the community (an educated workforce, infrastructure changes, etc.) and what the community can expect in return (new jobs to be filled by a local, educated workforce, modifications to transportation infrastructure, monetary compensation, etc.) A clear understanding of the needs and demands arising from the technical system helps build confidence within the community that it can fulfil those needs or helps the community choose to opt out with clear understanding of the facts.

Perhaps more importantly, the two-way conversation enables the technical community to understand the concerns from potential hosts and gives an opportunity to address early misconceptions regarding the efforts and deployment, removing biases, and collecting relevant and valid concerns.

The inclusion of stakeholders will identify the social system requirements early in the nuclear waste storage/disposal infrastructure design process, including siting, to ensure community concerns and goals are identified and addressed by design. This avoids retrofitting solutions into the system (which could be costly), or having social requirements negotiated out due to technical limitations that could have been addressed in design. The latter could result in lack of trust, community rejection, political barriers, or delays and denial of permits/license to operate. The CE and STS Design process, while time-consuming when engaging all the necessary stakeholders, has the benefit of inclusion and transparent communications resulting in a greater likelihood of successful siting and long-term operations of a nuclear waste management facility.

5. FURTHER INFORMATION

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