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Expert assessments of the state of U.S. advanced fission innovation

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ABSTRACT

Deep decarbonization in the U.S. will require a shift to an electrified society dominated by low-carbon generation. Many studies assume a role for nuclear power in the new energy economy, and the nuclear industry anticipates an eventual transition from light water reactors to advanced, non-light water designs. The development of these advanced reactors is emblematic of the type of dramatic change that is needed to transition from fossil fuels and deeply decarbonize the energy system. The Office of Nuclear Energy (NE) in the U.S. is entrusted with the allocation of public sector expenditures for this transition, but there is little to show for its efforts; no advanced design is remotely ready for deployment.

Here, we report results from structured interviews we conducted with 30 nuclear energy veterans to elicit their impressions of the state of U.S. fission innovation. Most experts assessed NE as having been largely unsuccessful in enabling the development of advanced designs. The interview results highlight the importance of leadership and programmatic discipline, and how their absence leads to poor performance in driving change. Responses point to the likely demise of nuclear power and nuclear science in the U.S. without significant improvements in leadership, focus and political support.

1. Introduction

Deep decarbonization in the U.S. will require a shift to an electrified society dominated by low-carbon generation (Pathways to Deep Decarbonization, 2014). Many studies suggest that the most cost-effective way to do this is with a portfolio of technologies that include a role for nuclear power (Pathways to Deep Decarbonization, 2014; Lester, 2016; Dickenson and Sharp, 2013). However, the economic and institutional challenges facing large light water reactors (LWRs) make a rapid expansion in the use of current nuclear technologies difficult. For decades, energy planners have envisioned a move to standardized, factory-manufactured systems and non-light water designs, which would alleviate some of the challenges associated with LWRs, including their high cost and concerns about both safety and waste (Nuclear Energy Agency, 2009; Assembly of Engineering of the National Research Council, 1977; The National Academy of Engineering, 1979; Committee on Nuclear and Alternative Energy Systems, National Research Council, 1982). In the U.S., stewardship of this transition rests with the Department of Energy's (DOE) Office of Nuclear Energy (NE), an applied research and development (R & D) office charged with developing and demonstrating advanced reactor technologies (Department of Energy Office of Nuclear Energy Advanced Reactor Technologies Office Mission, 2016). Despite repeated roadmaps indicating a commitment to innovative designs, NE has failed to fulfill this mission, and no advanced reactor design is remotely ready for deployment.

In a recent analysis of NE's budget expenditures over the past two decades, we found that it lacks both the funding levels and programmatic focus to execute its non-light water reactor mission (Abdulla, et al., 2017). NE's difficulties in fulfilling its role highlight a fundamental challenge to major transitions in the energy system. How can limited government support for emergent energy technologies be allocated judiciously, and specifically, how can NE better enable nuclear innovation? Answering these questions ultimately requires expert judgment. Here, we report results from interviews we conducted with 30 senior nuclear energy veterans from across the enterprise—all with extensive knowledge of NE and the history of nuclear technology development—to elicit their impressions of the state of nuclear innovation in the U.S. and its likely future prospects.

2. Method

We conducted semi-structured interviews with subject matter experts that lasted two hours on average, making this one of the most

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in-depth assessments of the challenges facing nuclear innovation. Semi-structured interviews were necessary for three reasons. First, metrics of program success are opaque—where they exist at all—and require more than numbers to explain. Second, diagnoses of performance and prescriptions for improvement varied across participants, and thus we could not use the closed-form lists normally found in highly structured elicitations. Indeed, standard elicitation techniques focus on assessment of key variables and elicit probabilistic distribution functions (PDF) around those variables. For this paper, adopting this standard model would have severely limited the number of questions we could explore: most could not be parsed into the traditional PDF-elicitation framework. Third, some limited structure was necessary to ensure that the questions delivered and content elicited remained consistent across multiple months. The interview protocol engaged the experts in a wide-ranging assessment of the various organizations involved in the nuclear enterprise. It investigated past and current performance, elicited suggestions for improvement, and assessed the likely future prospect for nuclear fission under two distinct scenarios. The protocol was thus broken down into sections, as shown in Fig. 1.

The Institutional Review Board (IRB)-approved protocol included the use of both open response queries and a number of basic ranking exercises. Prior to beginning the interviews, we explained the purpose of our study as an "assessment of the state of advanced fission innovation in the United States", taking care to provide no hint of bias. Question design was reviewed carefully to avoid leading or priming. During ranking exercises, participants' rationales for ranking order were elicited only after these rankings were made. Examiners made counter-arguments, where appropriate, to assess the strength of the positions taken by participants. Participants received no prior notice of the nature of the questions, and no compensation was provided. All interviews were conducted by two interviewers at the offices of the participants, one of whom served as primary interviewer, while the other severed as primary recorder. Following each session, the primary recorder transcribed notes in electronic form. Both interviewers reviewed and approved the final interview transcript.

Cumulatively, the 30 experts have over 750 years of experience in the nuclear enterprise, and were drawn from the federal government (both DOE and Congress), the national laboratories, academia and industry. Participants were recruited by first assembling a list of recognized experts in the area of advanced nuclear innovation. This list came from both a literature review and an assessment of national lab, DOE and Congressional staff leadership listings. Requests for participation were then sent to a large group (> 50); these explained the motivation and duration of the proposed interview. The thirty who accepted include people who designed the reactors, materials and fuels responsible for establishing U.S. technological and industrial leadership in nuclear energy. In order to assure frank discussion, we promised anonymity, given the experts' positions and the sensitivity of the subject matter. This was disclosed as part of a pre-interview informed consent form. The entire protocol is reproduced in the Supporting Information (SI).

3. Step 1: Exploring the current state of advanced fission innovation (AFI)

In our opening section, we asked the experts to reflect on the current state of U.S. AFI, and then to reduce their diagnosis to a few words or phrases. Twelve of thirty gave a vague assessment using terms such as "evolving" and ten were distinctly negative about the state of innovation. Eight provided a description that reflected a current state that was trending in a positive way. Responses were clearly tied to each expert's frame of reference, with seasoned veterans of the enterprise—active in the 1960s and 1970s—taking a decidedly more negative tone than more recent entrants into the field, who remember only the dearth of activity in the 1980s and 1990s. The majority believes that efforts to innovate have failed to deliver tangible results. Most elements of the enterprise have atrophied, including the available facilities, the commercial nuclear supply chain and the human capital. One expert characterized it as "on the brink of death," with the vague "evolving," "nothing new," "aimless," "academic," and "disjointed" five common descriptions.

Among those who provided vague or negative assessments, more than half qualified this by noting that the growing level of interest in AFI is "exciting" or "encouraging". They deem this a "modest" revival, considering the dearth of activity that existed just a decade ago. The reason for this excitement is the involvement of young entrepreneurs, most of whom are supported by private capital.[1] Even the most optimistic experts conceded that the current level of activity is primarily academic. At best, "all we have is [intellectual property], not actual products", and it is therefore unclear where this modest revival will lead or what it will accomplish.

To examine the reasoning behind their assessments, we asked participants to explain how the state described had been reached. The universe of explanations was limited enough for us to summarize their responses in Table 1 below, which breaks these down into three categories according to the level of optimism exhibited in their short characterizations of the state of AFI. Notably, even those experts who were optimistic about the state of innovation in the field qualified their responses. While they saw reasons for hope, they uniformly acknowledged the sheer scale of the task that lies ahead and all noted that past efforts have failed. As the table shows, their positive assessment was based on broader cultural changes that are driving the need to re-examine nuclear power as an alternative.

We next asked each expert three key related questions that set the stage for the rest of the interview: 1) Which entities should lead the AFI enterprise? 2) What should be the goals of AFI in the U.S.? 3) What should be the role of NE within the larger advanced fission enterprise?

Opinions regarding who ought to lead the advanced fission enterprise differed. Responses from 21 of the experts fell on a spectrum that ranged from DOE on one extreme to private industry on the other. The group that endorsed the latter view saw government as a facilitator that ought to provide private vendors with its existing knowledge base, facilities and resources. Skeptical of this notion, the group that endorsed DOE noted the scale of the task at hand, the fickleness and short-term priorities of private enterprise and the wreckage of previous private ventures. Of the nine who fell outside this spectrum, four saw the national laboratories as the repository of AFI knowledge, and thus its natural leaders. Three experts considered research universities the obvious leaders in innovation, while only two trusted the utilities to lead.

There was agreement about the goals that must motivate research, development and deployment activities. The enterprise's goal, and its ultimate measure of success, should be to ***build a demonstration unit***. In order to achieve that goal, the enterprise ought to pay attention to developing the technical and regulatory framework within which one or two new advanced technologies would operate, and make sure that the product fulfills customers' needs.

As for the role of NE, more than two-thirds of the experts declared that they ought to be mainly a facilitator, or enabler, of research. They should conduct research that is high-risk and potentially high-reward, and maintain the facilities that buttress innovation in the industry, as opposed to micro-managing its activities. Because NE has been the steward of public monies dedicated to AFI, we dedicated a section to assessing their past performance.

[1] Although over thirty new startups exist in the U.S. alone, private funding is dominated by a small number of companies with wealthy backers, such as TerraPower.