Thirty Years of Social Science Research on High-Level Nuclear Waste:

Achievements and Future Challenges

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Abstract

Research on high-level nuclear waste management has focused on technical and scientific issues since the U.S. National Academy of Sciences first studied the problem in the mid 1950s and recommended long-term disposal in deep salt formations. In this review, we trace the development of the problem's definition and its associated research since socioeconomic, political and policy issues were first given consideration and nuclear waste management became recognized as more than a technical issue. Three time periods are identified. First, from the mid 1970s to early 1980s, initial research explored institutional dimensions of nuclear waste, including ethics. The second period began in the early 1980s with a concerted effort to solve the problem and site nuclear waste repositories, and ended in the mid 1990s with minimal progress in the U.S. and general stalemate in Asia and Europe (with the notable exception of Sweden). This phase accelerated research on risk perception and stigma of nuclear waste, and elevated a focus on public trust. Great attention was given to repository siting conflicts, while minimal attention was placed on ethics, equity, political systems, and public participation. The last period, since the mid 1990s, has been characterized by continuing political stalemate and increased attention to public participation, political systems and international solutions. Questions of ethics have been given renewed attention, while research on risk perceptions and siting conflicts continues. We frame these periods in a broader context of the shifting role of applied social scientists. The paper concludes with a general discussion of this research area and prospects for future research.

Key Words: High-level nuclear waste (HLW); Public trust; Repository siting; Risk perception; Stalemate

Introduction

High-level nuclear waste (HLW) management has been a political issue for over 30 years. Even if radioactive waste was recognized as an important problem in the 1960s, it was only in the 1970s that it turned into a highly controversial issue, when nuclear power itself began to be questioned by society. When the topic became a central question for political and societal concern, its social dimensions were increasingly recognized and integrated into research. Thus, social research on HLW also has a history of over three decades. In this paper, we will review the international research since the mid 1970s on social aspects of HLW management. Having said this, it should be noted that physical scientists and engineers since the late 1940s have published articles in the *Bulletin of the Atomic Scientists* or in *Science* in which social issues of nuclear energy and radioactive wastes were briefly discussed.

The social science research focus on HLW management will be seen as being under ongoing pressure for change. On the one hand it has evolved in relation to changing views on the technical handling of wastes (e.g. disposal vs. storage) and changing patterns of policy-making interests. On the other hand the research has followed in line with many social science research priorities and more far reaching societal trends.

The purpose of this paper is to map the shifting focuses and clarify trends in the standard international social science literature that focuses on HLW management. By conducting such a literature review, we have sought to clarify the pattern of changing research foci so that we may discuss these and better understand their salience. What achievements have been made in the more than three decades of research and what can be learnt for future research? The context for our effort is 30 plus years of technological research and development as well as scientific

analyses that have yet to produce an example of a successfully implemented final repository in any country.

A few major limitations were placed on this review. Firstly, the paper includes literature that analyzes the management of HLW generated by the civil nuclear power industry only, as opposed to military use. Secondly, we have largely omitted the literature on spent fuel reprocessing. For those interested in matters concerning nuclear weapons, nuclear proliferation, and reprocessing, we strongly recommend the work of von Hippel (e.g. 2008). Thirdly, while consultants, international organizations, nuclear waste companies, non-governmental organizations, the nuclear power industry, regulatory agencies, and other stakeholders have published many important reports, pamphlets, and the like, with a few major exceptions these materials fall outside the purview of our objective to focus on the standard international social science literature. A fourth limitation is that we have approached the literature as an exponent of a research area of inter-disciplinarity to which scholars in a wide range of disciplines from the social and behavioral sciences and humanities contribute (economists, geographers, political scientists, philosophers, psychologists, sociologists, social anthropologists, etc.). Put differently, we have not distinguished between different academic disciplines in our review. Such an endeavor would almost certainly be of disciplinary interest but falls outside of our purview as well.

We will begin with a brief description of the technical aspects of the waste disposal problem and the option of long-term storage. In the following three sections of the paper we will delve into three somewhat overlapping time periods. Indeed, this outline as such represents a main result of the paper, namely that the shifting focuses and trends in the standard international

social science literature can be divided into three time periods. From there we turn to the concluding section, which summarizes the main findings and discusses ideas for future research.

Technical Management of Wastes: Disposal vs. Storage?

The problem of HLW has been historically defined as requiring long-term isolation of radionuclides from the human environment. Students of nuclear waste management are well aware that there are several technical options for accomplishing this. These include: disposal under the seabed (Deese, 1977); disposal in the Antarctic ice sheet; partitioning of actinides and ejecting them from Earth by rocket; transmutation of actinides in nuclear reactors; and various versions of deep geologic disposal in very stable formations. An additional option, ocean dumping of HLW, was dismissed by the 1970s as technically unsound, and environmentally and socially unacceptable. Ocean dumping of HLW was banned when the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter of 1972, usually called the London Dumping Convention, entered into force in 1975 (Hamblin, 2006), which went on to ban the dumping of low-level radioactive wastes in 1993.

Scientists and policy-makers reached a consensus by the late 1970s that deep geological disposal should be pursued for spent fuel and HLW management. This conclusion does not change if spent fuel reprocessing and breeder reactors are used, although transmutation could ease the waste management problem in a breeder economy by potentially decreasing the waste volumes and greatly shortening the half-lives (Goble, 1983, p. 149). Sub-seabed and Antarctic disposal options were eliminated early because of large scientific uncertainties and controversies, while rocket launch was eliminated as overly risky and costly. Interim management options, such as storage in dry casks for approximately 100 years or collection in a centralized, short-term

monitored retrievable storage (MRS) site have been actively considered but are not seen as long-term solutions. Consequently, deep geologic disposal has been the policy throughout the nuclear-powered world and has determined research priorities for over thirty years.

The consensus on deep geologic disposal went unchallenged for 15 years, until the publication of an article by Flynn et al. (1992a), their later monograph (Flynn et al. 1995), and books by Shrader-Frechette (1993) and Easterling and Kunreuther (1995). Flynn et al. argued based on their work for a board of the U.S. National Research Council that it was time to reconsider all options for HLW management, including dry cask storage and spent fuel reprocessing. They based their recommendations on the dismal track record of the U.S. program in general, and the experience in developing a socially and technically acceptable repository at Yucca Mountain, Nevada in particular. Importantly, the authors argued that until and unless the various social issues are given the same attention in HLW management as the technical ones the program was doomed to fail. Shrader-Frechette, in turn, argued forcefully on both ethical and scientific risk assessment grounds against near-term deployment of deep geologic disposal.

Keeney and von Winterfeldt (1994) published related and more analytical work around this time, which considered alternatives such as temporary above ground storage at a centralized facility or next to nuclear power plants. If either of these is pursued, the analysis assumed that a repository would be built in 2100 for waste not subsequently recycled. The analysis treated various uncertainties, including the possible future uses of HLW. The objectives used to compare alternatives included: concerns for health and safety, environmental and socioeconomic impacts, and direct economic costs, as well as equity concerns, indirect economic costs to electricity ratepayers, federal government responsibility to manage HLW, and implications of theft and

misuse of these wastes. This analysis found that currently building an underground repository at Yucca Mountain is less expensive than other strategies by the equivalent of $10-50 billion.

Later analysts have also urged a reconsideration of the technical options for HLW management. These have included Flueler (2001), who introduced the concepts of "integral robustness"—both technical and societal— and “monitored long-term geologic disposal”. In the HLW case, it was argued that waste disposal must have a conservative, passively stable design with built-in control and intervention mechanisms. This "extended" final disposal concept emphasizes technical robustness, recognizes evaluation demands (for a potential break-off of a project) and enhances process-based transparency.

Throughout the various discussions of the HLW problem by policy-makers several important dimensions have been considered, which have not always been explicit. These include the timeframe for resolution, i.e., long-term (final) vs. medium or short term (interim). A variety of tradeoffs may be involved here. Secondly, an associated objective to the timeframe is whether or not the problem is conceived as a question of proper disposal vs. interim storage, and whether or not retrieveability should be an associated feature of the system. The importance of retrievability hinges on questions of science, such as whether future knowledge of disposal risks may reverse present day decisions, as well as policy, such as the future use of spent fuel through reprocessing in a breeder economy. Finally, additional considerations revolve around the question of safeguarding HLW, both to technically isolate wastes from the human environment, as well as to monitor the wastes against future risks of theft or accidents by human intrusion.

Changing Research Foci

London, Stockholm & Washington, We have a Problem! – the Achilles Heel is Diagnosed

We begin with the influential UK Royal Commission on Environmental Pollution, established in 1970. The first condensed conclusion reached by this body in its nuclear power report of 1976 was illustrative of the socioeconomic approaches towards HLW management at that time, i.e.: ”There should be no commitment to a large programme of nuclear fission power until it has been demonstrated beyond reasonable doubt that a method exist to ensure the safe containment of long-lived radioactive waste for the indefinite future” (Flowers, 1976, p. 202; the Sierra Club made the same pronouncement in 1975). In April 1977 the Swedish Parliament passed a groundbreaking law that echoed the standpoint that was put forth by Flowers. This, the so called Nuclear Stipulation Act ("Villkorslagen"), prescribed that the proprietor of a reactor had to meet one of two conditions before the reactor can start operating: "Operating permission is to be granted only if the reactor owner has established a contract for reprocessing of spent nuclear fuel, and, further, has proven how and where a completely safe final storage facility can be constructed for the highly radioactive waste, or has proven how a completely safe final storage facility for spent, un-reprocessed nuclear fuel will be constructed and where it will be located" (Johansson & Steen, 1978, pp. 49-51).

Around the same time the U.S. government also demonstrated its serious attention to the HLW problem. First, President Jimmy Carter appointed a task force in 1977 to review Department of Energy HLW management programs. This was followed by the establishment of the much broader Interagency Review Group on Nuclear Waste Management (IRG), later in 1977. The IRG was rather candid in its assessment of the waste problem, and called for the resolution of institutional issues and development of deep geologic repositories for HLW disposal (IRG, 1979).

National governments, international and multilateral organizations, power engineers, and the nuclear industry all knew during the atomic age that, eventually, the highly radioactive residues from the nuclear fission in reactors needed to be properly taken care of in a technical sense. It was not until civil nuclear power generation developed into a highly controversial political issue, however, that civil nuclear energy was seriously questioned, not least by the developing environmental movement. At this time, HLW management was transformed into a politically delicate problem and, hence, HLW became the Achilles heel of nuclear power (for analysis of the growing public and environmental group opposition to nuclear power in the U.S. in the 1970s, see Kasperson et al., 1980). This is also to say that, given the strong market and government incentives for both continuing and expanding nuclear power, policy-makers became increasingly dependent upon social scientists and their knowledge of how to handle HLW as a political problem. Once waste management had become the Achilles heel of nuclear power and, hence, a vexing political dilemma, social scientific studies of HLW management began to be conducted.

The UK's Flowers (1976) report provided a comprehensive exposition of political, ethical, social and technical problems with HLW management. In many respects its approach to the problem also reflected the policy-making agenda of the time. It thus regarded permanent disposal in geological formation on land or below the ocean floor in stable areas as the only two reasonable options (though both methods remained to be proved reliable), underscored that waste should be solidified (vitrification) into blocks of glass, and stressed the importance of international collaborations for testing disposal options. Notable is that the report leveled severe criticism against British waste management authorities and industry for giving inadequate attention to the problems of HLW (c.f. Kearney & Garey, 1982 for the U.S. case). From today's

perspective, it is also noteworthy that the approach and methods (technical, organizational, etc.) for handling HLW had not yet been nationalized in the 1970s (Flowers et al., 1976, pp. 131-164; see La Porte, 1978, p. 24 for similar perspectives). For example, the Flowers report maintained that environmental interests are not served by returning HLW to the country of origin in cases when foreign fuel is reprocessed in the UK, and gave greater importance to the principles of disposal in best available geological formations and minimization of transportation than to the principle of national responsibility, the latter of which is largely incontestable today. The principle of best available geological formation for final disposal of HLW and, hence, the argument about the need for an international solution, was also stressed by Angino. He argued that the absence of a uniform international approach for handling HLW was increasingly troublesome since the number of countries committed to the use of nuclear energy had been growing and, hence, the volume of wastes continued to grow (Angino, 1977).

Rochlin (1977) was among the first authors to address the ethical considerations of HLW management. In comparison with today's generational principle, the standard of ethical responsibility that Rochlin put forth was less demanding. The present generation has neither the power nor the moral obligation to pass on to the future an unchanged world. However, since every act of the present generation has the potential to fundamentally change future lives, "our minimum ethical obligation is to examine most thoroughly the potential consequences of present actions, to acknowledge them openly, and to minimize the potential for irremediable harm" (Rochlin, 1977, p. 29). To ensure continued isolation of HLW from the biosphere, in the face of both social and geological uncertainties, and to anticipate likely consequences of technical or judgmental errors, Rochlin proposed that the performance of any suggested HLW management scheme should be judged against two criteria – "technical irreversibility" (i.e. site security) and

"multiplicity" (of waste sites, and redundancy of barriers). To follow his proposition, Rochlin maintained, would be to provide a clear basis for open and conscious policy choice (Rochlin, 1977).

By applying concepts from decision theory to nuclear waste management, Goodin presented results that could support the ethical basis of the generational principle. His main argument was that none of the economists' and philosophers' traditional arguments for discounting the future will work for nuclear waste disposal. It is towards what Goodin called the "uncertainty excuse" that nuclear waste management levels a deathblow. Such an excuse applies regularly to "modest" uncertainties concerning probabilities alone. But since nuclear waste is distinguished by a more profound form of uncertainty, the expected utility calculus is impossible, which in turn undermine the decision rule built on discounting (Goodin, 1978). Goodin's analysis is an exceptional case among the publications reviewed here, since he explicitly strove after theoretical and philosophical generalizations, using HLW management as but an empirical case study.

In another influential early article, La Porte (1978) diagnosed that insufficient attention had been paid to the operational aspects and "10-year problems" (in contrast to the 1,000-year problem) of the U.S. HLW management system "when it grows to the scale necessary to handle wastes produced by a fully deployed plutonium economy". La Porte argued for assembling appropriate information that could improve the quality of policy development when selecting acceptable HLW management systems and inform public debate concerning such systems. The proper processing of such a comprehensive bulk of information, assuring a greatly increased predictive capacity, would, however, necessitate that a reasonably well-informed and tested social scientific theory of economic, social and political dynamics was developed (cf. Lipschutz,

1980, pp. 155-174). La Porte's analogy with scientific laws, applied to interpret engineering data that renders it possible to predict the technical dynamics of complex engineering systems, is telling for his ambition to transfer the knowledge constitutive interest of the physical scientist, i.e. to control and predict phenomena, to the social sciences (La Porte, 1978).

One theme that is recurrent in several social scientific publications during the late 1970s and early 1980s is the distinction between reprocessing and direct disposal of spent nuclear fuel. From all that a reprocessing and plutonium economy entails, social scientists have especially stressed those consequences that have to do with non-proliferation, dangerousness in worldwide transporting (logistics), and, hence, the need for international regulation and possibly also regional disposal facilities (Flowers, 1976; Rochlin, 1977; La Porte, 1978; Kasperson et al., 1980).

Referring to contemporary social science research and opinion polls, Kasperson et al. described how waste disposal during the 1970s developed into the primary obstacle to the public acceptability of nuclear power, first in the U.S. and Germany (Kasperson et al., 1980; Rucht, 1980). As an obstacle it is all the more complicated since there appeared to be a great divergence in public and expert risk assessment: experts tend to perceive HLW as a problem that can be managed, whereas the public apprehends HLW as a largely unsolvable matter (Kasperson et al., 1980). Observations such as the one made by Kasperson et al. were among the first contributions to what soon would become a major focus area within social science research on HLW management.

Determined Efforts to Solve the Problem

An early and notable attempt to constructively address the political and social issues that arise with HLW management was made by Lee (1980). In his article, Lee critiqued the "consultation and concurrence" policy for HLW proposed by the U.S. IRG in 1979, especially the vexing and conflict-laden concept of concurrence (IRG, 1979). In its stead, he recommended use of an innovative "siting jury" that could represent state and local interests, and perhaps applied in the siting of away-from reactor storage facilities for spent fuel. Further discussion on consultation and concurrence, and public participation in HLW management more generally, was provided in the book edited by Colglazier (1982). This volume was completed before passage of the U.S. Nuclear Waste Policy Act of 1982, and also compared waste management policies and programs in several industrialized countries. Deese's chapter was especially instructive, as it discussed factors that might increase national consensus, such as the partial decoupling of progress in waste disposal from the future of nuclear power (Deese, 1982).

Lee was also a member of an influential panel of the National Research Council, chaired by Kasperson, which reviewed the socioeconomic aspects of HLW management in the U.S. (NRC, 1984). The report made 19 findings on the rudimentary state of knowledge, and most notably called for an ambitious program of public participation as well as follow-up research and analysis. Unfortunately this advice went largely unheeded by the U.S. government, and other than a substantial effort made by the State of Nevada (of course in its own best interests), little research funding on the socioeconomic issues would be forthcoming. Moreover, within a few years the public participation in the U.S. HLW program would essentially end, with the Department of Energy focusing its investigations exclusively on Yucca Mountain.

With the founding of the Society for Risk Analysis in 1980 and establishment of its journal in 1981, a new focal point for analysis and debate about the challenges of radioactive

waste management would emerge. Indeed, *Risk Analysis* has gone on to become the primary outlet for the dissemination of scholarly research results on this subject, whether based on social sciences, physical sciences, engineering, management sciences, ethics or other perspectives. Yet, perhaps surprisingly, *Risk Analysis* did not publish its initial article on nuclear waste management until 1987.

Another edited book, by Kasperson (1983), provided a comprehensive treatise on equity and nuclear waste management. Equity issues were divided into legacy (intergenerational), locus (locational), and labor-laity (different standards for radiation protection). The first two concerns were also addressed by the conceptual model of Solomon and Cameron (1985), an early example of a HLW siting proposal to directly incorporate ethical considerations.

There was an acceleration of repository siting research conducted in the mid to late 1980s, especially in the U.S. as attempts were made to implement the Nuclear Waste Policy Act. Especially valuable in this period was the work of Merkhofer and Keeney (1987), who used multiattribute utility analysis to explicitly characterize the advantages and shortcomings of the final candidate sites considered in the U.S. Unfortunately, these analyses were rendered moot when Congress amended the Nuclear Waste Policy Act in late 1987 to focus the siting investigations only on Yucca Mountain. By this time the U.S. program was widely seen as a failure, which would have reverberations abroad, though many siting efforts continued. For excellent accounts of the history and highly conflict-laden HLW siting process in the U.S. this period, see Carter (1987), Jacob (1990), and Colglazier and Langum (1988). HLW repository siting activity also picked up in Western Europe and Japan during this time. Detailed reports on these programs were provided for the UK, Sweden, West Germany, France and Japan (Openshaw et al. 1989; Berkhout et al., 1989; and Carter, 1987, pp. 233-368). Finally, a

comprehensive global survey of nuclear waste repository siting patterns was provided by Solomon and Shelley (1988).

There was general confidence among the governments of nuclear states in the mid 1980s that the HLW problem would be solved in the not too distant future. As a result, there was little research at that time to follow up Deese (1982) to better understand issues of political systems and fragmentation, and how these might facilitate or hinder HLW management solutions. A major exception was Solomon (1988), who began a broader discussion on the possibilities for reform of the major nuclear states, and especially Carter (1987), who provided a detailed examination of the HLW stalemate and emphasized the importance of building greater public trust. Related issues that began to be addressed included public participation and trust in the siting process (Kraft, 1988), and HLW transportation and public perception of shipment risks and emergency response (Resnikoff, 1987), including regulation of ocean shipments (Van Dyke, 1996). Kraft and Clary (1991), in particular analyzed the strong opposition to as Eastern site for HLW disposal in the U.S. as an example of the "Not in My Backyard" model, and concluded that basis for the opposition was much more complex.

By the late 1980s and early 1990s it was apparent that efforts to successful site radioactive waste repositories were stalled in most countries and the stalemate would likely be prolonged. Berkhout (1991) provided an account of the relative role of government, industry, and the public and the context of technical vs. political decision-making in HLW management in the UK, Sweden and Germany. Blowers et al. (1991) produced a similar but broader account, which also covered the U.S. and France. The latter volume linked several dimensions of political context to the outcomes of conflict over repository siting in the various countries: political institutions, public participation, waste management policy, and political geography. Carter's

theme of public trust is further developed by the authors, and also by several chapters in the volume by Herzik and Mushkatel (1993). The latter monograph included chapters on institutional and organizational issues surrounding repository siting, waste storage, transportation, and discussion of a constructive alternative to the "Yucca Mountain solution."

A rich literature developed in the 1990s on risk perception and HLW management. In one paper, Kunreuther et al. (1990) suggested that the willingness of Nevada residents to accept a HLW repository at Yucca Mountain depended upon subjective risk factors, especially the perceived seriousness of risk to future generations. Perceived risk was shown to depend in part on the level of trust placed in the U.S. Department of Energy to manage a repository safely. Opposition to a local repository did not decrease significantly if compensation (in the form of annual rebates) was offered to residents. Related work by Slovic, Flynn & Layman (1991) showed that these risk perceptions were deeply rooted in images of fear and dread that have been present since the discovery of radioactivity. A third paper in this series, by Flynn et al. (1992b), developed a structural model to examine the relationship between public risk perceptions, trust in risk management, and potential economic impacts of the current repository program using a multivariate method called covariance structure analysis. The results indicated that perceptions of potential economic benefits did not have a significant role in predicting support or opposition to the repository program (cf. Slovic et al., 1991). On the other hand, risk perceptions and the level of trust in repository management were closely related to each other and to positions on Yucca Mountain.

A series of papers published in 1993-1994 compared and contrasted the risk perceptions regarding HLW of scientists, engineers, the business community and the general public. Flynn et al. (1993a) surveyed attendees at the American Nuclear Society meeting on this issue. They

found that nuclear industry experts may have very different opinions from the public about risks associated with HLW, on trust in nuclear-waste program managers, and on costs and benefits of a repository project. Their images of a repository indicate a vastly different conceptual framework within which their opinions are formed. Around the same time, Barke and Jenkins-Smith (1993) examined similarities and differences in risk perceptions, particularly regarding HLW, and policy preferences among 1,011 scientists and engineers. They found significant differences in patterns of beliefs among scientists from different fields of research. For example, life scientists tended to perceive the greatest risks from nuclear energy and HLW management, and preferred the strongest requirements for environmental management. Finally, Jenkins-Smith and Bassett (1994) conducted a mail survey in Colorado and New Mexico to examine differences between scientists and members of businesses and environmental groups in their expressed perceptions of risk and also their assessments of the certainty of their beliefs. The authors found connections between perceived risk and uncertainty, and a greater tendency to update risk assessments from a position of greater initial uncertainty.

Another series of papers assessed the risk perception of HLW risks in regional case studies. These included the study by Flynn et al. (1993b) of the "Nevada Initiative", whereby the American Nuclear Energy Council attempted to re-educate citizens on the benefits of HLW, which backfired; MacGregor et al.'s (1994) survey of public reactions of HLW transportation through rural Oregon; and the Bassett et al. (1996) study of the perceptions and attitudes of local residents in Illinois and Michigan toward the storage of HLW at nearby nuclear power plants. Internationally, Hinman et al. (1993) compared survey respondents in Japan (Tokyo) to those in the U.S. Pacific Northwest with regard to risk perceptions of 30 activities, substances and

technologies. They found that in both countries, HLW disposal had one of the highest levels of dread.

While many of the repository models are necessarily abstract or mathematical, empirical research has also been conducted on citizens' views toward HLW repository siting. The volume compiled by Dunlap et al. (1993) was noteworthy in that it included public reactions to the preliminary HLW siting proposals in Texas and Washington States, content analysis of public testimony, and rural vs. urban differences in views of Nevada residents toward the Yucca Mountain proposal, and impacts on the Las Vegas convention business.

While only modest research on the ethical considerations of HLW management was conducted in the 1990s, a powerful case against the Yucca Mountain proposal was made by Shrader-Frechette (1993) on both scientific and ethical grounds. In particular, she emphasized the predominance of value judgments in repository risk assessment, and gave numerous examples of the use of subjectivity in estimating and evaluating repository risks. This leads to problematic inferences, widespread uncertainties, all of which clashes with a variety of equity considerations for future generations. As a result, an aboveground MRS was recommended as the preferred option over the next century.

Research in the mid 1990s also addressed the potential socioeconomic effects of HLW repositories, both positive and negative. A comprehensive review of this vast literature and its inter-disciplinarity, at both the federal and state levels, was provided by White et al. (1994). Metz (1994) used research on a broader range of nuclear facilities to question the notion that HLW storage or disposal facilities would necessarily lead to negative effects because of public feelings of dread and stigma. This argument was strongly challenged by Slovic et al. (1994) based on the stigma literature.

It should also be noted that some important theories have emerged from the applied empirical work on the socioeconomic aspects of HLW management. The most important such theoretical developments have come in social amplification theory, with applications to a larger range of problems (Kasperson et al., 1988; Renn et al., 1992). Additional spin-off theory has come in the areas of stigma theory and social trust analysis (Slovic et al., 1991; Kasperson et al., 2001; Earle and Cvetkovich, 1995).

Despite the problematic experiences with HLW repository siting from 1980-1995, and often critical nature of the literature, we close this section with a discussion of two constructive studies. First, the book by Easterling and Kunreuther (1995) explored the HLW siting dilemma and public opposition in the U.S. but went on to propose a voluntary process that they believed could be acceptable and successful (cf. Gregory et al., 1991 and Easterling, 1992 on the role of incentives and fair siting rules). This is basically what is happening in Sweden. The authors recommended compensation to address equity concerns and economic efficiency, once concerns with health, safety and environment are addressed. Lastly, Ballard and Kuhn (1996) developed and tested a facility location model for HLW facility siting in Canada. The model was based on successful Canadian siting processes related to hazardous waste and low-level nuclear waste facilities, as well as attributes of facility siting found in the literature. Survey results demonstrated that while over half of their respondents did not support the Canadian Nuclear Fuel Waste Disposal Concept during public hearings, the majority favorably rated the proposed facility location model. A cautionary note is later offered by Hunold (2002), however, who has argued in the Canadian case that voluntary approaches are no more successful in HLW repository siting, due to a typically and excessively local conception of public participation.

Failure to Solve the Problem

The third period – since the mid 1990s – includes papers published in a wide range of journals. These papers were mostly published in cross-disciplinary journals for environmental issues, policy questions, and risk research. *Risk Analysis* is still the primary outlet, but since the establishment of London-based *Journal of Risk Research* in 1998 there has been a second journal frequently presenting results from social science research on HLW management.

Throughout this period there is a continuing flow of case studies that have addressed resistance and stalemates against HLW disposal. Some examples are risk communication in the search for underground laboratory sites in France by Barthe and Mays (2001), the non-violent resistance against radioactive waste disposal in Germany by Fischer and Boehnke (2004), psychological factors regarding HLW facility sitings in Japan (Tanaka, 2004; Kugo et al., 2008) and South Korea (Chung et al., 2008), and the multiple causes of the ultimate failure of the Yucca Mountain project in the U.S. (Ewing & von Hippel, 2009). Thus, a wide range of aspects of the subject has continued to be scrutinized in the last fifteen years.

On the other hand there have been studies on what is considered the more successful case of Sweden (e.g. Sundqvist, 2002), and to some extent Finland (Litmanen, 1999; Macfarlane, 2006) and Canada (Durant, 2007; 2009). Most notably, findings by Sjöberg and Drottz-Sjöberg (2001) and Sjöberg (2004) underscored the support by local citizens for a HLW repository in Sweden, an example where citizens have been supportive due to reasons of a moral and societal nature. But even if the Swedish siting process has been relatively successful, it has not fully succeeded since a final decision on HLW has yet to be made. As a result, the overall view of the policy-making process from the later part of 1990s to the present is still one of general stalemate. The only exception to this rule is Finland, where a HLW site has been chosen near Olkiluoto in

Eurajoki, though a survey of three potential sites has shown that significant public opposition has existed at this location, just less intense than elsewhere (Litmanen, 1999).

A range of articles has continued to pay attention to the lack of public trust for repository projects, which is the general explanation for stalemate. Detailed surveys and interviews were conducted, e.g. by Bassett et al. (1996), on the public attitudes towards a central repository in Yucca Mountain, Nevada, and by Jenkins-Smith & Silva (1998) in the case of the U.S. military waste facility in New Mexico. In Bassett et al. (1996), the authors compared local attitudes and risk perceptions of repositories with those found at nuclear power and reprocessing plants, and reported divergent results. A stringent conclusion is put forward by Blowers (1999), in case study comparisons between the US, UK, France and Germany, that a HLW solution can only be accepted when it meets both the best technical standards and is acceptable to the public.

By this time the question on how to solve the HLW problem was given a two-folded answer. Firstly, the importance of giving priority to local public opinion was underscored, and secondly a shift from closed to open decision-making processes was recommended. Ballard and Kuhn (1996) and Murphy and Kuhn (2001) explicitly sought to upgrade the authority of local government and processes of local citizen participation. They proposed devolution of power to stakeholders and citizens *throughout* the siting process, which they argued would produce a sense of fairness and give open access to information on the project and its consequences. It is by the creation of a local repository that the future of the nuclear power industry ultimately will be decided, according to Blowers (1999). This is not necessarily a good thing, however, according to Kuhn (1998), who considered with some skepticism the transformation of the HLW waste issue from the national to local level as a way to isolate it, as the regional dimension thereby might be forgotten.

At this point in time it is useful to consider whether social science research findings have been considered in HLW management and disposal decisions, and the general answer is clearly no. The main exception is Sweden, where government policy greatly involves local communities in the decision-making process and to give them a veto at each stage, and to only site a repository where there is clear local support (OECD, 2003). While a final decision on HLW disposal in Sweden has yet to be made, this sensitivity to local opinion is vital. This is in start contrast to the U.S. situation, where the Yucca Mountain decision was made with no regard for public opinion since legislation was enacted in 1987. While a HLW repository there was officially approved by the federal government in 2002 (Solomon, 2009), the decision was reversed by President Obama's Administration in early 2009 and the policy is in the process of starting over (Ewing & von Hippel, 2009). More indeterminate cases exist in Finland, where a HLW repository siting decision was made in 2001 where there was some, though not strong, local opposition, while other nuclear states are in various stages of learning these social lessons and have further delayed their final decisions (Andrén & Strandberg, 2009).

There are indications of a changing role for social scientists within this research area. This policy-making stalemate is considered as situated within the society and therefore not considered a technological issue. Meeting this situation, social scientists regard themselves as problem solvers. There has been much criticism and conclusions that policymakers and governments should make better use of their knowledge (e.g., Flynn et al., 1995; Freudenberg, 2004). Most importantly, social scientists began to actively make recommendations for conducting the social management of HLW. These can be quite concrete, e.g. consultations with the public, meaningful participation by local residents, and negotiations with local governments and local elections (Easterling & Kunreuther, 1995; Ballard & Kuhn, 1996; Kraft, 2000; Endres,

2009). A stepwise decision-making process has been suggested, so that specific circumstances and institutions of each country can be best handled (Pescatore & Vári, 2006). The boundaries between social science and social engineering are in these cases quite loose, but stricter when the recommendations are on a more general level, suggesting principles of transparency, trust and democracy (Dawson & Darst, 2006).

Participation and deliberation are keywords for many articles. Of special interest is one series that delves into the problematic aspects of reforming public participation. Petts (2004) sets up an ideal of deliberative processes that are informed, effective and analytic, and draws attention to the barriers to establishing such (cf. Endres, 2009). Another angle to this theme is that processes of deliberations might undermine public trust instead of promote it, if not adequately modeled (Chilvers & Burgess, 2008). Lidskog and Sundqvist (2004) argued that a real deliberative process must include possibilities for changing the concept by the negotiating parties, otherwise the process risks being considered as a way to co-opt the public to the goals of the policy makers. Along these lines, Durant developed the concept of 'boundary organizations' that through deliberative processes seeks to control the citizenry. Considering the programs for HLW disposal in the U.S, UK, Sweden and Canada, his conclusion is that these organizations "are busily carving out a political terrain in between government steering mechanisms (intervention, regulation, and issue definition, for instance) and ceding to local autonomy" (Durant, 2007, p. 518).

Several articles developed HLW management as an issue of the relationship between on the one hand science and technology, and on the other hand society. This can be considered a matter of different interests between the technical and the various social perspectives (Falcone & Orosce, 1998). Others have stressed the far reaching consequences of nuclear technology and the

waste it produces. Short and Rosa (2004, p. 135) proposed four principles for HLW management: 1. Recognition of the inevitability of uncertainty and agreed-upon ways of dealing with it; 2. Development of 'communities of fate' and of trust among all stakeholders; 3. Building on common values related to the environment and to the wellbeing of future generations; and 4. Adherence to the rule of law. It is the recognition of uncertainty that leads to the importance of common values, or the ethical standards that are most convincingly put forward by Shrader-Frechette (1997), giving philosophers a place alongside social scientists within this research area.

Waste ethics has been a common theme since the early 1990s (e.g. Posner & Streifzuge, 1990). By the turn of the 20th century it was discussed as an intergenerational principle, which stipulates today's duties towards future generations, to not hand over to them greater risks than we put on ourselves. This is scrutinized in relation to principles of fairness and welfare (Shrader-Frechette, 2000; Okrent, 1999; Ahearne, 2000), and attempts are made to reconcile it as a question of economic behavior, to be discounted across generations (Belzer, 2000). In the 21st century, ethics is regularly referred to in HLW research and was the subject of a special issue of *Risk Analysis* in December 2000 (see also, e.g., Wilson, 2000; Shrader-Frechette, 2005; Marshall, 2007).

Methodologically, recent years have seen additional comparative studies like the ones that occurred in the 1980s and early 1990s. For example, Lidskog and Andersson (2002) and Högselius (2009) present mostly descriptive analyses that have covered up to 32 countries. Högselius and Kaijser (2007) contribute a more developed comparative analysis of Germany, Russia and Japan, whereas Andrén and Strandberg (2009) compiled seven national case studies on HLW management in Canada, France, Germany, India, Sweden, UK and the U.S. together into a special issue of *Journal of Risk Research*.

Finally, the theme of internationalization has also evolved in this literature in the last decade. As we have already seen, it is not new to look beyond the nation as the object for research, as several comparative studies on HLW management among nations were completed in the mid to late 1980s and thereafter. More recently, there have been articles concerned with proposals for international HLW repositories in Australia (Holland, 2002), Russia (Dawson & Darst, 2005), and as a matter of principle (Marshall, 2005). The article by Darst and Dawson (2005) is most innovative in studying the internationalization of HLW management, putting controversies within the EU regarding its policy for radioactive wastes in relation to proposals for exporting the material to Russia (Ziegler & Lyon, 2002).

What to Learn from this? Ideas for Future Research

A main result of this paper is the identification of three research periods in the HLW management area, each characterized by broader contexts. The first period comprised the beginning of HLW research in the social sciences, from the mid 1970s to the early 1980s. Protests against the atomic bomb and its further testing began in the 1950s. But it was not until the 1970s that public protests against nuclear power commenced, initially in Germany and the U.S., with a special mistrust against the fuel reprocessing industry and its potential link with nuclear proliferation. It was in this setting of a growing awareness of the risks and long lifetimes of radioactive wastes from nuclear power production that the problem was first considered an Achilles heel. So, starting in the mid 1970s the social sciences, like the policy makers, had a period of awakening, realizing that “we have a problem!”

The second period was framed by an optimistic air, with the overall embracing ambition to solve the radioactive waste disposal problem once and for all. The time period began in the

early 1980s and continued until the mid 1990s. This problem solving emphasis (and greatly increased research funding) gave social scientists a new role to play as policy analysts and advisors, offering innovative methods for approaching an unwilling public. Its institutional frame includes expanding risk research, and new scholarly journals and research centers. Indeed, *Risk Analysis* has been the journal in which social scientists have published most frequently on this issue. Furthermore, the growing general emphasis on interdisciplinary environmental research has established multidisciplinary settings for social scientists working on HLW management issues.

The third and most recent period dates from the mid 1990s and is ongoing, when the research area reacted to the failure HLW management to "solve" the waste problem in most countries. In this time frame the earlier established research trends for the most part continued, and reinvigorated consideration of the themes of ethics and equity appeared. As national solutions have not had great success, the theme of internationalization of HLW disposal is now returning (after being briefly considered in the mid 1980s) and may be gaining salience.

As a first reflection for discussion around the result of this review of the standard international literature, social scientists seem to have become increasingly interested in contributing with their research approaches and results to social consensus and acceptance enhancing, policy-making processes (deliberative stakeholder involvement such as panels, focus groups, and interviews etc.). A major explanation for this could be that the notion of political and social consensus has grown all the more important, due to a policy shift in late 1980s and the early 1990s from looking for the best available geological formations for HLW disposal to one that is good enough. With this shift, it was no longer necessary to build facilities at the one and only best place in each country, but only to find a place suitable for other reasons (e.g. isolated

but still reachable by transport, already laden with other toxic substances, a willing local community, etc.). This means that the methodologies of social scientists have become more important than ever. Anxious policy makers now turn to social scientists in several countries in efforts to solve the HLW problem. This is also to say that social scientists could not resist being deeply involved with policy makers. As a consequence, in the social sciences, as in geology, the main thrust of the policy-making agenda has become paradigmatic.

We are not arguing that most of this research is methodological unsound or premature in any significant way. However, we recognize that social scientists tend to lack self-confidence in their knowledge constitutive interest and, hence, in defining the problem and setting the research agenda, which applies to much of what we have seen in the nuclear waste arena, similar to many other areas of sponsored research. One example is the concept of trust. Emphasized by Carter (1987) as a missing component in siting processes, public trust became a major research theme in the 1990s. By then it had been adopted by policy makers as the way of overcoming stalemate. Cadres of social scientists are exploring components of trust and varying degrees of trust for waste disposal among populations, aiming at producing recommendations for further advancements of facility siting implementation. The same pattern can be observed regarding the concept of public participation. From the early 1990s, the Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD) wanted decision-makers to respond to demands for citizen participation, and organized five workshops from 1991-1997 on information and public participation issues (Riotte, 2005; NEA, 1997). However, only lately has the use of such participation been criticized (Hunold, 2002; Lidskog & Sundqvist, 2004, Durant, 2007). To a minor degree this observation also applies to the concept of ethics. In some countries, ethical principals were introduced by policy-makers in the 1980s. Several social

science researchers took notice of this shift, and the philosopher Shrader-Frechette (1993) developed ethical principles as an important part of her criticism of geological disposal of HLW in the U.S. But after its adoption by IAEA (1995) and NEA (1995) it has become almost paradigmatic to talk about ethics, though mostly in a loose way.

This reflection of proximity between social scientist's research approaches and the policy standards of the focus area is due to a further distinctive feature of utmost importance for HLW management research. Starting as a technical subject, HLW research was organized around technical projects. The frame was set by technical knowledge and engineering ideals of finding practical solutions. It was only when real-world hindrances of social character occurred that usage of social science research came into force. To speak with Jürgen Habermas (1972) one could maintain that social scientists actually adopted the knowledge constitutive interest of the physical scientists, i.e. to control and predict the facility siting process.

Another way of putting this is to note the two dimensions of social sciences, i.e. on the one hand being an extended part of state administration and on the other hand having its critical tradition of producing autonomous knowledge. Social research should turn more to the second dimension. But one could still ask why? Is it not a "good" thing to help governments and other policy makers to find a working solution to the radioactive waste problem? What is wrong with social scientists following policy-makers on nuclear waste management? Once again we turn to Habermas (1972). The answer is simply that the strength of social science is within a knowledge constitutive interest that aims at understanding and explaining society, which does not accept existing relations without a scrutinizing eye and establishes a critical distance to power relations and thus possibilities for informed discussions among the public and a process of democratic decision making. The alternative is that social scientists denigrate themselves to plain

investigators. Reverting to a comprehensive issue that has spurred us to carry out this review, and venturing to counterfactual reasoning: one may actually ask oneself whether there would have been greater successes in establishing final HLW repositories if social scientists to a larger extent had relied upon the strength of their knowledge, and hence contributed more directly and fruitfully to the policy-making processes?

However, researchers cannot and shouldn't take on such counterfactual questions, but it is indeed essential and worthwhile to try to explore the relationship between scholarly knowledge production and social development. For that reason (and our first idea for future research), we hope that social scientists, to a larger extent than thus far, will carry out systematic analyses of the relationships between scholarly knowledge production and publication and high-level politics, policy-making, facility siting, and eventually the successful and/or unsuccessful establishment of a final HLW repository. Within the field of science and technology studies (STS) one can find studies that explicitly aim at coming to grips with the relationship between the formal (and informal) production of knowledge and processes of policy-making. One example is approaches that study such a relationship within the theoretical scope of so called boundary objects and boundary discourse. For instance, Durrant (2006, 2007) analyzed arguments and statements on Canadian nuclear waste management in documents that borders between scientific inquiry and policy-making. The strength of such an approach is at the same time a weakness: tracing and deconstructing the dynamics of a boundary discourse necessitate a deep-seated acquaintance with the constituent actors of the policy/epistemic community, which by definition leads up to a methodological dependence on single case studies. Hence, a promising objective for future social scientists' analyzes of HLW management would be to bring

together the strength of STS with the effectiveness of the comparative methodology of economic history, geography, political science, or sociology.

In conformity with the last step of the previous logic, another finding from the results of this literature review is that there is a preference for case studies. Irrespective of whether the specific object of the empirical analysis of HLW management is high-level politics, particular policy measures, siting of single facilities, or trust-enhancing processes, the single case study is the most frequent method. The advantage of the single case study is that it can disclose local contexts and thereby uncover deeper understanding of the phenomena that characterize the case as such. The drawback, however, is that it does not produce generalizable explanations. Put differently, the skilled case study methodologist runs the risk of being unable to see the forest for the trees, while approaches that build on a historical and comparative methodology have an explanatory potential (see e.g. Blowers et al., 1991; Högselius, 2009; Andrén & Strandberg, 2009). This brings us to our second idea for future research, namely that it would be preferable to develop methodological pluralism and triangulation generally (on triangulation c.f. Harvey & MacDonald 1993), and comparative and historical approaches specifically.

That the lion's share of the reviewed literature is published in the journals *Risk Analysis* and *Journal of Risk Research* reflect that to a very large extent, scholarly social scientific research on HLW management has been increasingly articulated within the field of risk research. One could actually argue that risk research to a large extent originated from the pressing problems and stark public opinions on how to manage HLW, and the serious questioning of nuclear energy as such. For one thing, however, the risk research field has expanded and developed during the last three decades, not least by focusing on non-nuclear applications. Since HLW management as a social and technical phenomenon relates to and concerns much broader

matters than risk, the great uncertainties and challenges that it poses for society today would be more thoroughly analyzed and comprehended if the wide range of public policy theories and methods was actively utilized. Jones & Jenkins-Smith (2009) recently made the same point in the context of theories about the public policy process. As a third idea for future research, we thus hope that future social scientific studies on HLW will continue to actively explore dimensions of the problem besides risk. Following the first point made above, it would actually come very natural to study "nuclear waste management" as an empirical case study among others. Just to take some examples it would be relevant and highly interesting to see that HLW management in different countries served as empirical study objects for: a political scientist, dedicated to the testing of theories of the relationship between the quality of governing institutions and economic and political performance; a geographer, interested in understanding the relative roles of pro nuclear (cultures) communities, transportation issues and geological and technical criteria in siting policies; an economic historian interested in pursuing research founded in theories around historical institutionalism and focusing on interest group's actions and developments; a legal researcher interested in analyzing country-specific senses of justice and rule of law in several countries; or an historian of ideas and science interested in unfolding the stream of ideas over time and space. If one observes the various concepts that have been utilized in HLW research in the last 30 years, it is an obvious fact that the conceptual fashions and developments in social science disciplines are reflected in this research. That concepts such as acceptance, trust, participation, and dialogue have been recurrent in HLW research illustrates that it does not and should not comprise a field of its own. Furthermore, if the various disciplines of the social sciences in the future would succeed in making room for the study of HLW management as a social-empirical object among others, it is also to be hoped that more researchers realize the

potential for comparing HLW management with other social phenomena (e.g. climate policy, sustainable development, energy security).

A final reflection has to do with the downside of specialization within scholarly social science inquiry, and relates to some extent to the methodological reflections above. To understand the dynamics behind national level HLW politics, compounded by party politics and ideological standpoints, the policy-making processes characterized by bargaining between politicians, bureaucrats, and industry in which researchers also contribute, or the tense course of events that arise as local residents' and environmental organizations' mobilized reactions in relation to the implementation of facility siting, certainly calls for concentrated and specialized empirical analysis. At the same time, an integration of approaches is called for (see Strandberg, 2000 for an endorsement of such approaches). As is convincingly shown and argued by for example Berkhout & MacKerron (2009), Hocke & Renn (2009), Durant (2009), and Solomon (2009), the failure to establish a HLW repository in the U.K., Germany, Canada and the U.S., respectively, can best be understood when the analysis includes high-level politics of energy and HLW, policy-making, and the tangible processes for facility siting. This brings us to our fourth and final idea for future social science research on HLW management, namely that it should be capable of developing an integrating capability so that all strengths that come with research specialization could be combined into a truly cross- or trans-disciplinary approach.

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