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Title: THE LOS ALAMOS NATIONAL LABORATORY NUCLEAR VISION PROJECT

Author(s): EDWARD D. ARTHUR, NMSM
RICHARD L. WAGNER, JR., NMSM

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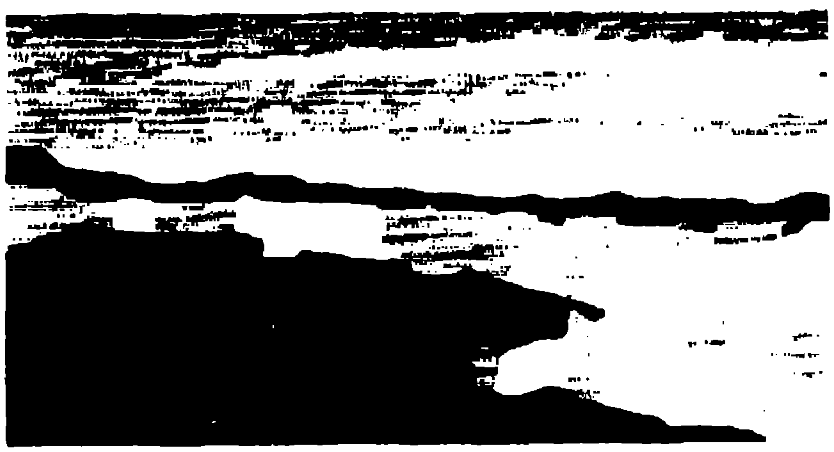

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The Los Alamos National Laboratory Nuclear Vision Project

Edward D. Arthur and Richard L. Wagner, Jr.
Los Alamos National Laboratory
Los Alamos, New Mexico USA

Abstract

Los Alamos National Laboratory has initiated a project to examine possible futures associated with the global nuclear enterprise over the course of the next fifty years. All major components are included in this study—weapons, nonproliferation, nuclear power, nuclear materials, and institutional and public factors. To examine key issues, the project has been organised around three main activity areas—workshops, research and analyses, and development of linkages with other synergistic world efforts. This paper describes the effort—its current and planned activities—as well as provides discussion of project perspectives on nuclear weapons, nonproliferation, nuclear energy, and nuclear materials focus areas.

Introduction

A little over 50 years ago, the beginning of the Nuclear Age set into motion developments in military and civil applications of nuclear science and technology that shaped history through significant impacts on international, national, and local aspects of society.

Dramatic global political changes, including the end of the Cold War, have provided both an opportunity and incentive for an examination of the future of the global nuclear enterprise. The Nuclear Vision Project at Los Alamos National Laboratory is intended to explore how the evolution of "things nuclear" might progress globally over the next half century. Essential elements of this study include the future of nuclear energy and other civil applications; nuclear weapons and proliferation; the institutions associated with, and public opinions about, nuclear science and technology; and environmental and other related issues. The general objective of the project is the creation of a "global vision" which seeks to manage the balance between realising nuclear technology benefits globally and reducing nuclear dangers. As examples, nuclear technology benefits can include nuclear energy, particularly in its contributions to meeting global energy security and environmental objectives, other nuclear technology applications in medical and industrial areas, and, from some perspectives, the past and possible future roles of nuclear weapons in stabilising international relations. Nuclear dangers include areas related to the use of nuclear weapons in future conflicts, growth in the numbers of states possessing or developing nuclear weapons, illegal flows of fissile nuclear materials, and the role of nuclear weapons (real ones or latent capabilities to produce them) as a source of tension in international relations.

The efforts described here occur in an environment of past similar efforts, current efforts underway at institutions such as other Department of Energy laboratories, or efforts planned to begin shortly. As examples, these include the U.S. National Academy of Sciences study on excess weapons plutonium[1], the American Nuclear Society study on protection and management of plutonium[2], the International Nuclear Societies Council vision for the second fifty years of nuclear energy[3], the Sandia National Laboratories project on the role of American nuclear weapons in the first quarter of the twenty-first century[4]. The U.S. Nuclear Posture Review, the Atlantic Council study on the future of nuclear power in Asia and globally[5], and the proposal[6] for an international commission to assess the future of nuclear power globally.

Goals

The Nuclear Vision Project does not attempt to predict the future but rather aims to explore alternative futures and their implications. In doing so, we hope to gain a deeper understanding that will guide actions at Los Alamos, where the great majority of research and development occurs in areas directly linked to nuclear technology. In addition, we would like project results to provide credible information relevant to current and future policy dialogues on major nuclear issues.

As will be described, the project seeks to examine alternative futures in the context of important realities that carry implications for the future: the increasing demand for nuclear energy in east Asia, the growing global inventories of nuclear materials, an increasing demand for energy coupled with the finiteness of many current fuel sources, the reduction of superpower stockpiles, the increasingly rapid diffusion of nuclear technical knowledge and capabilities across the globe, and the risks of nuclear weapons proliferation and of proliferation of other weapons of mass destruction. Exactly where these current situations may lead is unknown, but it is certain that the future will be shaped both by unanticipated events and intentional actions. The task of this project is to think broadly about what is desirable and possible in the context of some set of future realities, without departing from the realm of possibility.

Methodology and Approach

Our attempts to examine a "global vision" are conditioned by the practical need to tie long-range objectives back to near-term actions and decisions through achievable steps and milestones. This goal and the process involved are illustrated schematically in Figure 1. As is indicated, the process starts

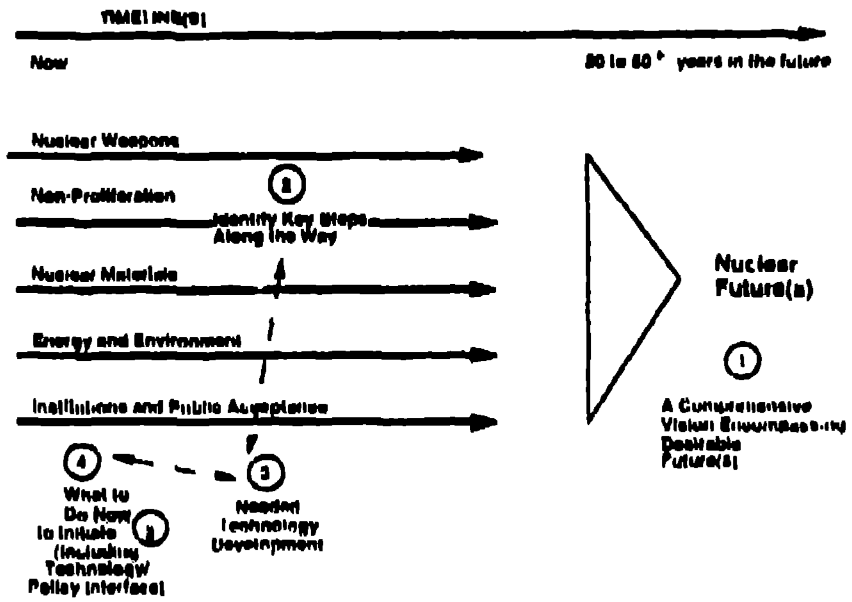

Figure 1. Methodology for developing a global nuclear vision.

with the positing of desirable futures (endstates) 20 to 50 years into the future. The decision to address a nominal 50-year horizon represents a realistic boundary given that technology development and implementation generally take decades. Some in the energy industry plan at least two or three decades ahead, and individual military systems, including ships, aircraft, and nuclear weapons, can remain in inventory for several decades. Such posited futures are intended to include the major nuclear-related elements shown in Figure 1 as well as to explore relationships among them. Linkages and impacts on outside factors associated with areas such as global stability and security or global, regional, and national energy security are under investigation as well. Finally, these posited futures will be tested against some series of scenarios that could impact them positively or negatively.

Once a set of nuclear futures has been proposed, the next step in the process involves identifying key technology, institutional interface, and policy steps that should occur along the way. Since expertise at Los Alamos National Laboratory lies primarily in forefront areas of technology development, identification of needed science and technology is a component of major interest to the project. The final step involves taking information developed as a result of the first steps to identify actions in technology, institutional, and policy areas that would allow one to proceed along a "roadmap" towards a desired nuclear future, or some major component of such a future. Examples of such a process are provided later in the paper.

To approach these complex nuclear-related areas, the project has been divided into three elements – internal and external workshops, internal Los Alamos research and analysis projects, and efforts to link work at Los Alamos with synergistic efforts throughout the United States and the world. Figure 2 illustrates the connectivity of these three essential elements. Development of both understanding and (hopefully) consensus on complex and interrelated global nuclear issues are intended products of the project, and its success will be measured by how and whether the fruits of the project impact actions and decisions.

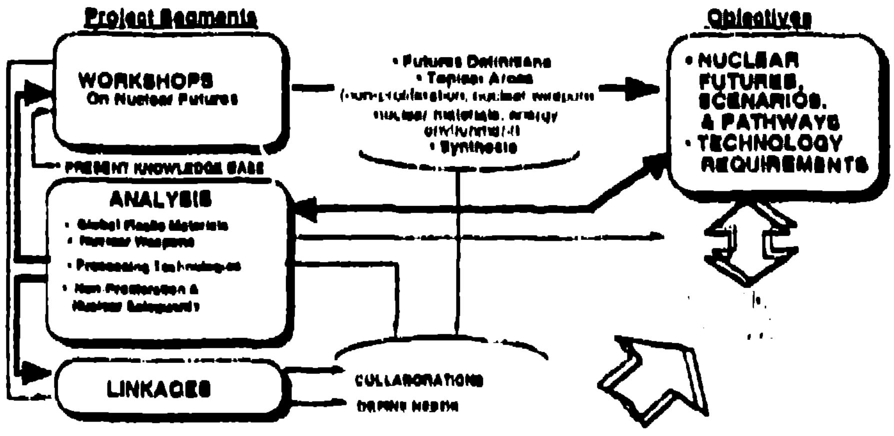

Figure 2: Los Alamos Nuclear Vision Project elements. The workshop component's duration at approximately 1 to 1 1/2 years; the analysis efforts are intended to last for approximately 3 years; and the efforts to establish linkages with synergistic efforts will be ongoing.

Workshops

Three workshops have been held on the topic areas outlined earlier. Each workshop was designed to include experts who contribute a broad spectrum of perspectives and opinions, ranging from general support of the benefits of nuclear technology to legitimate concerns about present and future nuclear activities.

The first workshop (August 1995) was entitled "Securing the Nuclear Future". Its objective was to launch the Nuclear Vision project by discussing the present status and long-term implications of the global nuclear endeavour. The title was chosen to reflect the theme of searching for desirable nuclear futures that achieve the project objectives outlined earlier and which deal with current and expected nuclear realities. Thus, nonproliferation, arms control, nuclear weapons, nuclear power, and nuclear material policies and options were topics under examination during this meeting.

A second workshop on "Nonproliferation and International Security" (November 1995) consisted of presentations and discussion on three major topics aimed at assessing the nuclear future in the 2015 time frame from nonproliferation and international security perspectives. These topics were a) the bases and implications associated with linking arms control and nonproliferation; b) material connections involving plutonium, future situations in the former Soviet Union, and nuclear smuggling; and c) research and development priorities in nuclear material, protection, control, and accountability areas.

The third workshop on "Nuclear Weapons and Stewardship Issues" (April 1996) used the policy concept of regimes (defined to mean collections of agreements, treaties, and capabilities that describe a global norm) as a major thread for discussion. This workshop examined the conditions, features, and issues associated with past, present, and future nuclear weapons regimes. The roles of nuclear weapons in the future, associated dangers posed by nuclear arsenals, and the challenges in defining desirable regimes for the future are examples of topics discussed at this workshop.

Future workshop plans include one on global nuclear energy and nuclear materials futures to be held later this year, tentatively entitled "Nuclear Energy and Global Security". Some issues and areas proposed for discussion in this workshop are described later in this paper. We also plan a small workshop on path gaming methods applicable to examination of scenarios and futures. A final meeting (in this workshop series) will focus on synthesising work from previous workshops (and other project activities) into a coherent vision statement.

Research and Analyses

To complement and support activities associated with workshops and efforts to establish links with other activities, a small internal effort exists to examine key issues. Areas under investigation include utilisation of models to examine future global and regional energy scenarios with emphasis on how nuclear power competes with other energy sources on the basis of drivers such as economics, environmental requirements, and proliferation drivers. A particular focus of this effort is understanding future dynamics of nuclear materials (growth of plutonium contained in spent fuel stocks, for example) and the development and application of quantitative methods for assessing proliferation risks associated with nuclear materials sources. In areas pertaining to future environments surrounding nuclear weapons, analyses are also being pursued that examine stability relationships and nuclear weapons roles in future multipolar international security environments. Discussion that follows in latter sections of this paper elaborates on current and future investigation activities.

Links to Related Efforts
A great deal of work relevant to the Nuclear Vision Project is being conducted outside of Los Alamos. By developing collaborations with appropriate individuals and groups throughout the U.S. and internationally, the project can establish important linkages to other institutions and centres of expertise associated with future nuclear issues and systems.

Discussion
Where do we stand in our appreciation of the nuclear future? To oversimplify somewhat, we will divide the discussion into two parts: 1) global nuclear energy and 2) nuclear weapons and (non)proliferation. To the extent that these topics are linked, it is mainly by the global nuclear materials posture—civil and military—and possible approaches to managing it. Part of our approach is to study the nuclear materials issues as they pertain to energy and to weapons and then to integrate them later in the project. Figure 3 provides an overview of research activities underway or planned for the project and illustrates connections between them as well as to global security and energy security externalities.

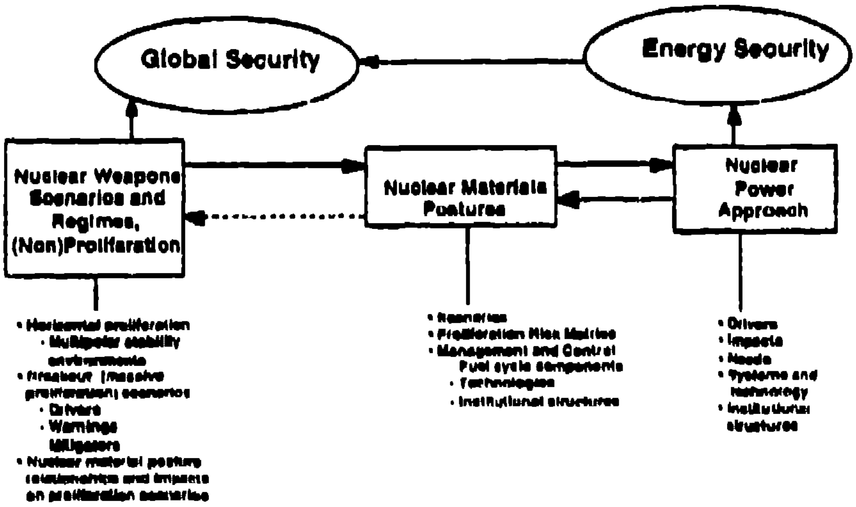

Figure 3: Analysis focus areas of the Nuclear Vision Project

Nuclear Energy and Nuclear Materials
Our approach to examination of nuclear energy scenarios focuses on 1) understanding drivers that can impact future trends in global, regional, or national use of nuclear power, and 2) issues associated with nuclear power and technology/fuel cycle/institutional approaches that deal with them. Both of these two areas work towards definition of a desired nuclear power "system" for the 2050 time frame—one that has strengthened attributes in areas such as economics, safety, and material management—and the steps that can lead up to it.

Key questions that guide our examinations include:

- What are the linkages and tradeoffs associated with future global energy security—including meeting energy and economic growth needs of developing nations—and nuclear power? How does the need to counter negative environmental factors, such as increased greenhouse gas emissions from fossil fuels, impact such relationships?
- What is the role of plutonium in future global nuclear energy scenarios? What technologies can prove effective in managing plutonium—both to utilise its energy content and minimise inventories that exist in a range of forms during functioning of the fuel cycle and which eventually must be disposed of in long-term geologic storage?
- What is the nature of the relationship between the growing global inventory of nuclear materials from civilian nuclear power and possible future dangers associated with proliferation of nuclear weapons? (See discussion in the following section on Nuclear Weapons and (Non)Proliferation.) Can proliferation risks from such material sources be quantified credibly so as to allow meaningful comparisons with other routes for material production? Are current safeguards for nuclear materials sufficient or are extensions needed? Could an inventory reduction strategy be applied? What technologies and institutional means would be attractive?

To provide an initial basis to address these topics, we utilise the Edmonds, Reilly, Barnes global energy, economics, environmental (E^3) model[7] modified to provide more detail in its treatment of the nuclear fuel cycle, particularly in the areas of reactor/fuel cycle economics and nuclear materials flow[8]. This framework allows a consistent set of projections for the amount (as competed on the basis of economics, resource availability, and projected energy needs) of nuclear power that could be implemented in each of nine major world regions, as well as globally. Figure 4 illustrates some initial (unbenchmarked) nuclear power and plutonium inventory scenario results[8] from this model. As

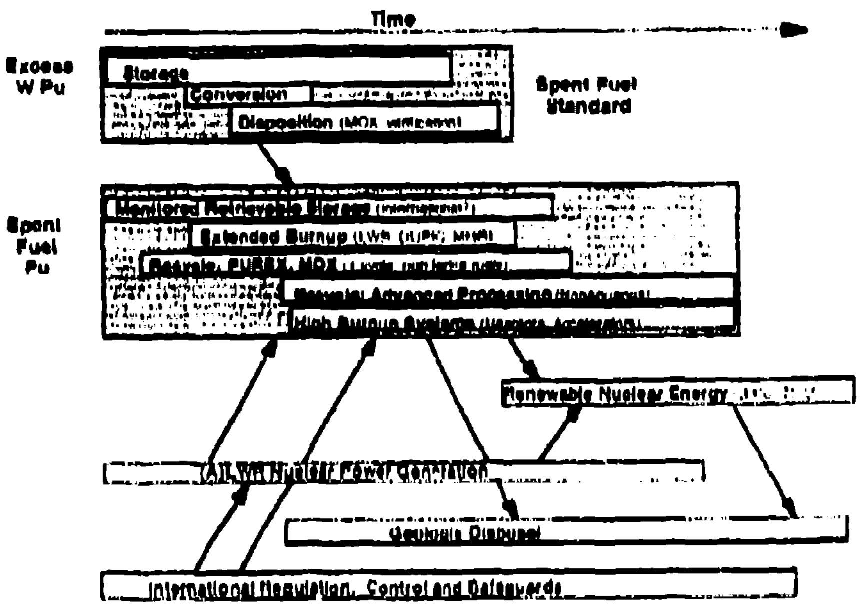

Figure 4 "Roadmap" example for strategies and technologies applicable to plutonium management.

indicated by these results, the model also computes expected material generation and flow amounts, types of material (high-level waste, plutonium in spent fuel, separated plutonium, etc.) for each major region versus time. The model can also be used to examine other future impactors on nuclear power, such as (economic) impacts of efforts to reduce fossil-fuel-produced carbon emissions through taxing structures. With this basis, it is possible to examine tradeoffs between disparate variables, such as reduction of global or regional carbon emissions versus increases in spent-fuel source plutonium, that might occur under energy strategies driven by environmental considerations (acid rain, global warming, etc.).

Results from such a model-based approach will be augmented with efforts involving two other areas. The first area deals with the assessment and grouping (by broad categories) of current and future national and/or regional situations regarding energy security. This effort is a "top-level" attempt (using much information obtained via the efforts to link the Los Alamos project with other synergistic efforts) to better understand how nuclear power may fit into energy security strategies, particularly those associated with Asian nations' development.

The second area of effort involves extension of past analytic work[9, 10] aimed at the quantification of proliferation risks associated with continued world-wide deployment of nuclear power. The focus of this effort is examination, from proliferation perspectives, of the rising global stocks of plutonium-containing spent fuel to assess risks against other material production/diversion routes that may be used for proliferation or massive nuclear weapon stockpile creation or reconstitution (see Nuclear Weapons and (Non)Proliferation discussion that follows). Features of interest for evaluating such weapons-related aspects of a global nuclear materials posture include:

- Total quantities of weapon-usable material—nationally, regionally, and globally—in various stages of a range of nuclear fuel cycles
- The chemical and isotopic forms of the material
- Future technologies for storage, security and monitoring, transportation, and separations
- Material location and how (physically and institutionally) it is secured and monitored.

This effort will also examine ways to address quantitatively long-term risk (in areas such as safeguards requirements and toxicity impacts) that are associated with the disposal of large amounts of spent fuel containing plutonium. For example, plans are underway to evaluate technologies and scenarios for recovery of plutonium in spent fuel after it has been placed in geologic disposal. Additionally, we want to examine methodologies used in decision analysis approaches[10] that discount the future importance of an issue such as accumulated plutonium. Such assumptions do not appear to account for long-term concerns, particularly those arising from uncertainties in institutional structures that may exist far into the future.

These tools can be used to assess several plutonium management strategies—a once-through cycle followed by geologic disposal, a plutonium recycle system possibly followed by plutonium breeding, or other fuel cycles such as thorium-uranium—from perspectives of short- and long-term risks arising from nuclear materials. We have already developed expanded models to predict growth in future plutonium inventories and to assess the impact of technologies for dealing with them. These studies[11] are also examining strategies and approaches for situating and managing operations within the nuclear fuel cycle. In summary, we are building a suite of tools that will allow us to evaluate alternative future nuclear materials postures in the context of a range of possible future regional and global security environments.

A desired end result from these efforts, as well as those developed in working relationships with other interested parties, is creation of a clearer picture of, and perhaps even a high-level roadmap towards, a desired nuclear power system endstate that would exist in the year 2050. (As P. Beck phrases it in his recent book[6], ". . . what would a successful nuclear power industry look like in the year 2050?") Such a picture would address fuel cycle options and strategies; institutions that might exist or be created to enhance nuclear power in areas such as safety, material management, safeguards, research and development, etc.; and components and technology associated with nuclear power in 2050. An example of one part of such a picture and the process leading to it is illustrated in Figure 5 where a progression of activities and technologies are identified for the management of plutonium from excess weapons and spent fuel.

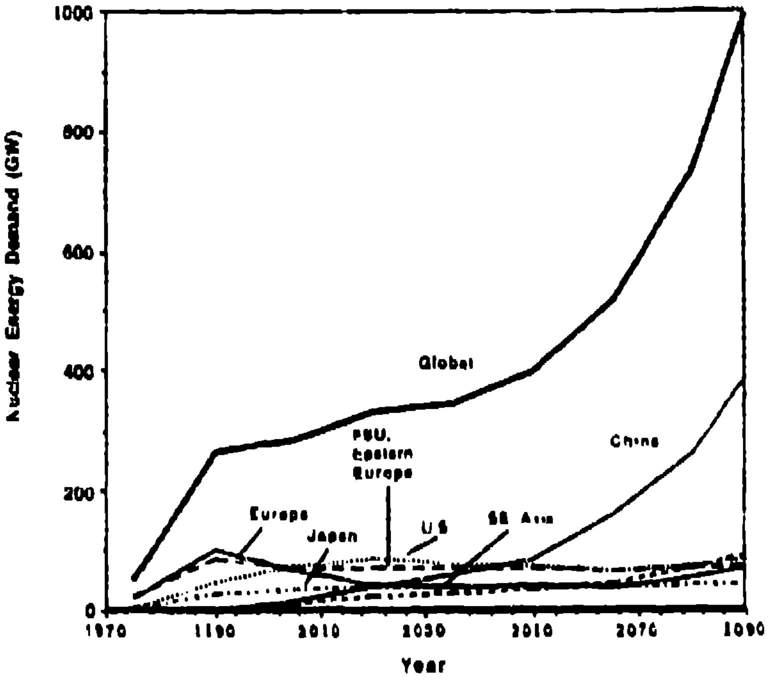

Figure 5a Model results for projected nuclear power demand (gigawatts of electric power)

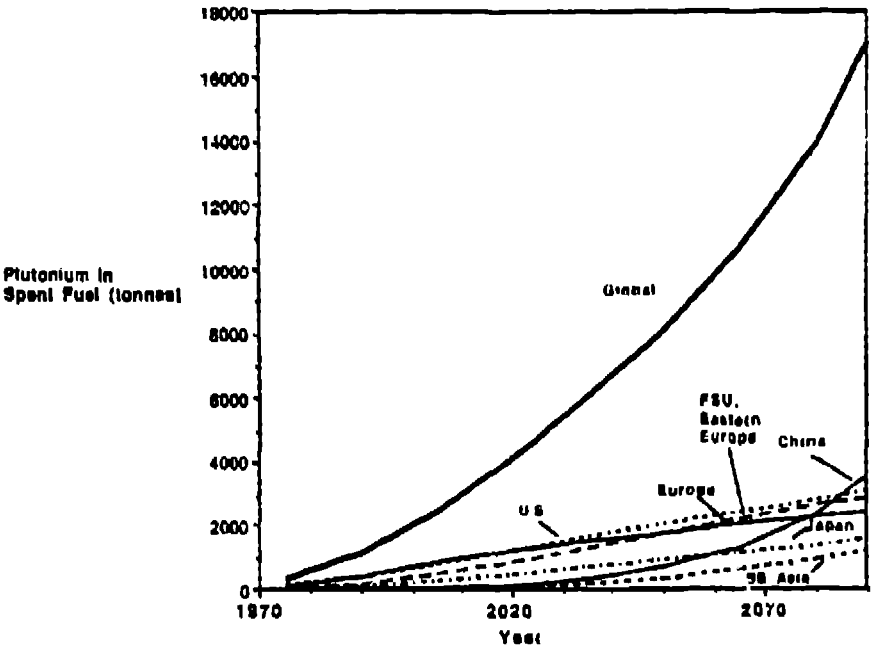

Figure 5b: Model results for projected plutonium inventories in reactor spent fuel (assuming a once through fuel cycle).

Nuclear Weapons and (Non)Proliferation

Two main themes organise our approach to thinking about nuclear weapons and (non)proliferation: 1) understanding the dangers associated with nuclear weapons over the long term and 2) understanding possible evolution of congruent behaviours—negotiated or tacit, unilateral, bilateral, or multilateral—on the part of nations/polities by which the dangers can be contained.

Containing future nuclear weapon dangers has many facets. For the purpose of this paper, we can group future nuclear weapon-related scenarios into two broad categories:

- "Canonical" horizontal proliferation of the general type represented by North Korea, Iraq, India/Pakistan, etc.

- Possible (further) future cases in which the world situation might develop in such a way that many nations/polities/blocs see a need (or an increased need) for nuclear weapons. Such situations could lead to possibly widespread, possibly rapid, competitive, horizontal and vertical, nuclear (re)armament ("breakout").

Canonical horizontal proliferation (the first category) is much thought and worried about and is, in a sense, the baseline case. In the project, we extend examination of this category to analyse instabilities (and therefore nuclear dangers) arising from two principal trends: 1) erosion of the classic conditions of deterrence (a bi-polar environment, U.S. versus Soviet Union) to include multipolar interactions and 2) reduction of numbers of nuclear weapons possessed by current nuclear weapon states coupled with possible expansion of the numbers of countries holding nuclear weapons so that possession of a "few" is amplified in its relative importance. We are also focusing attention on the "breakout" case for several reasons. First, it is simply less well understood. (It is also less understandable, because it would presumably develop, if at all, in the farther future, and because the only historical case--the early decades of the Cold War—is probably a poor model.) But more importantly, we feel that, in light of the destructiveness of nuclear weapons, prudence demands looking at such limit cases.

Attention to large scale (re)armament scenarios is suggested also because, as the global technology base grows and spreads over our long time horizon, the technology, science, and industrial capabilities needed for nuclear weapons development and production become more widespread. Capabilities to create substantial numbers of nuclear weapons (perhaps quickly) would thus be "latent" in many more nations' scientific, technological, and industrial bases (as they were in a few nations in 1942.) One might say that these nations will "have" "latent nuclear weapons."*

In reality, there is a continuum in a conceptual sense between the extremes represented by our two categories of scenarios. They could be connected over time as well; an increasing rate of canonical, horizontal proliferation could trigger a nuclear "breakout" as posited in our second category. Thus, we are conscious of the need not to give short shrift to nearer-term, "smaller," canonical proliferation—in part because of connections with larger scenarios, but also because it is important in itself.

However, the reverse—neglect of large-scale nuclear (re)armament scenarios—is too often the case in the current conventional wisdom. The emphasis on *preventing* proliferation (deeply embedded in the current, Nonproliferation Treaty-oriented regime) diverts attention from developing ways of *managing its consequence* if it occurs. Also, thinking about how to deal with a canonical proliferation crisis (including, possibly, a "next use" of nuclear weapons) often focuses almost entirely on the immediate outcome, with little attention given to longer-term consequences involving the full range of possible nuclear dangers.

With these considerations in mind, we are beginning to try to understand the dynamics of future nuclear weapon proliferation ranging from expansion of the numbers of nations having small numbers of nuclear weapons to the other bound of widespread, rapid, large-scale, n-sided, competitive nuclear (re)armament. Among other things, we are extending models used during the Cold War to analyse two-sided crisis-stability related to nuclear (and conventional) *forces-in-being*, to try to understand the much more complex scenarios involving *latent* nuclear forces and more parties.

We also want to understand more about the technological dimensions of future arms races as well, and it is here that connections with the global nuclear materials posture may begin to enter. In particular, what would be the pacing technological/industrial factors in future nuclear proliferation and possible (re)armament scenarios? Candidates are: availability of nuclear material; nuclear warhead design and fabrication (given nuclear material); and the nuclear weapons *systems* (delivery platforms, command and

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* The terms "virtual" nuclear weapons or "virtual proliferation" are sometimes used in somewhat the same sense. We prefer "latent," as it connotes time evolution—moving from latent weapons to real ones—which is of the essence of these scenarios.

control, etc.). Although it demands a much more careful look, general considerations seem to indicate that the latter two capabilities may exist widely in a more technologically/industrially advanced future. So, it will behove us to understand in some detail how alternative future nuclear material postures might affect nuclear material availability for weapon purposes in the scenarios we have discussed here.

A principal consideration is whether nations would construct dedicated military facilities or divert/access fissile material from the civil nuclear power fuel cycle. This national decision would be the result of a complex set of drivers including national and international incentives and disincentives, as well as a number of factors associated with routes that could be chosen for material production. These factors include items such as technical implementation, complexity, cost, detectability, capacity, and quality of material. Examples from history are of interest, but situations may be very different in the future. For example, separations technologies may be easier, but monitoring/surveillance may be better. In general, the more urgent the felt need for material, the more weight that could be put on access to (diversion from) the civil fuel cycle, either in terms of recovery of material from spent fuel or from reactor fuels themselves. Thus, figures of merit for evaluating alternative future approaches (dedicated reactors, clandestine separations facilities, uranium enrichment, civilian reactors and reprocessing facilities, alternative fuel cycles) should weigh heavily time to acquire materials and fabricate weapons under a variety of nuclear materials postures. The discussion on nuclear power and nuclear materials has highlighted our intended approach to this problem.

Of particular interest is the extent to which total quantities of potentially accessible material make a difference to such proliferation and breakout scenarios. To what extent, for example, is total quantity related to the efficacy of securing materials? This is one question, of many, related to what we believe are the two basic alternative strategies for nuclear material futures:

- Continued accumulation of spent fuel and other fissile materials requiring long-term security and safeguards

- Development and implementation of (possibly new) reactor technologies and fuel cycles such that, over many decades, total/regional quantities of fissile material of concern in the situations discussed above can be minimised (through long-term holdup in nuclear system cores, through reuse, and eventually through burndown of materials).

Implicit in the foregoing discussion is the idea that future global nuclear materials posture(s) might be more deliberately managed. As part of our project, we are beginning to explore how and to what extent a *concert of interests* (governments, multi-national and international political entities (already existing or new), industries, non-governmental organisations, etc.) might develop, or be developed, to this end.

Conclusion

March 17, 1996, was the 50th anniversary of the Acheson-Lilienthal Report, which began efforts to place all applications of nuclear science and technology under international control. Such international control did not come to pass. During the ensuing 50 years, a fabric related to nuclear affairs, civil and military, has been woven from threads of bilateral, multilateral, and international arrangements. The implications for mankind of the potential — for good and ill — of the energy of the nucleus of the atom are still global, indeed more so today than in 1946. The fact that this potential will continue to be a major issue in world affairs is a key driver for the Los Alamos Nuclear Vision Project

References

[1] J. Holdren (Chair), Committee on International Security and Arms Control, *Management and Disposition of Excess Weapons Plutonium*, National Academy Press, Washington, D. C., 1994.

[2] G. Seaborg (Chair), American Nuclear Society Special Panel Report, *Protection and Management of Plutonium*, American Nuclear Society Publication, 1995.

[3] M. Hori (Chair), International Nuclear Societies Council Fifty-Year Vision Committee, *A Vision for the Second Fifty Years of Nuclear Energy*, American Nuclear Society Publication, 1996.

[4] R. Rinne, Sandia National Laboratories, USA, personal communication, 1996.

[5] D. L. Guertin, The Atlantic Council of the United States, proposal for a study on "The Long Term Future for Nuclear Energy", personal communication, 1996.

[6] P Beck, as proposed in *Prospects and Strategies for Nuclear Power*, Earthscan Publications, London, 1994.

[7] J. Edmonds and J. M. Reilly, *Global Energy: Assessing the Future*, Oxford University Press, New York, 1985.

[8] R. A. Krakowski, "Global Energy Modeling in Support of Understanding Long-Term Nuclear (Materials) Futures (Work in Progress)", Los Alamos National Laboratory document, LA-UR-96-1931, June 1996.

[9] See for example, C. D. Heising, "Quantification of Nuclear Diversion Risks: Promises and Problems", Energy Policy 10, 101 (1982).

[10] P. Silvennoinen, *Nuclear Fuel Cycle Optimization: Methods and Modelling Techniques*, Pergamon Press, Oxford (1982).

[11] J. W. Davidson, R. A. Krakowski, E. D. Arthur, "Impact of Accelerator Driven Transmutation Concepts on the Management of Global Plutonium Inventories", Los Alamos National Laboratory document, LA-UR-96-1868, May 1996.