Invited Paper

Argonne National Laboratory:

An Example of a United States Nuclear Research Center*

Samit K. Bhattacharyya
Director, Technology Development Division
Argonne National Laboratory
Argonne, Illinois 60439
USA

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I. Background

The nuclear age was ushered in on December 2, 1942 under the stands of the Stagg Field at the University of Chicago. Enrico Fermi and his team of scientists produced the first sustained nuclear chain reaction on the CP-1 (Chicago Pile 1) facility. Shortly thereafter, a duplicate of this pile – the CP-2 - was constructed at a site roughly 50 Km from the University at the initial location of what was to become Argonne National Laboratory (Argonne). Argonne was formally inaugurated in 1946 with the basic mission of developing nuclear technology for civilian use. Subsequently, a number of other National Laboratories were established. Three laboratories - Los Alamos National Laboratory (LANL), Sandia National Laboratories (SNL), and Lawrence Livermore National Laboratory (LLNL) - were aimed primarily at the development, testing, and maintenance of nuclear weapons. The other laboratories - Oak Ridge National Laboratory (ORNL), Brookhaven National Laboratory (BNL), Idaho National Engineering and Environmental Laboratory (INEEL), Savannah River Laboratory (SRL), and Pacific Northwest National Laboratory (PNNL) - were multi-purpose laboratories like Argonne with part of their mission dedicated to the development of nuclear technology and its civilian applications. Taken as a whole, the U.S. multi-purpose laboratories fit the definition of a Nuclear Research Center (NRC) posed by the organizers of the Workshop.

Changing conditions have modified the missions of these National Laboratories drastically. With the end of the cold war, the defense missions of the three weapons laboratories have declined and each of them have increased the civilian nuclear component in their R&D portfolios. For the original multi-purpose laboratories, the missions have also been altered in response to the changing conditions in the nuclear power field. In this paper, I will focus on Argonne National Laboratory as an example of a U.S. NRC. I have spent my professional career at Argonne and can speak authoritatively on it. Challenges and opportunities faced by Argonne are typical of the U.S. multi-purpose laboratories and their discussion addresses the basic question of the evolution of the Nuclear Research Centers, which is the topic of this workshop.

The early focus of Argonne was the development of civilian nuclear power systems. The EBR-I reactor (CP-3) was one of the early successes and the NaK cooled HEU fueled system at the Argonne-West site was the first nuclear system to produce electric power. The early heavy water cooled and moderated reactor (CP-5) was also developed at Argonne, as was the first boiling water reactor (EBWR). In fact, for virtually every class of reactors in use, the early work up to and including prototype construction was performed at Argonne, the main exception being the gas-cooled reactor. The early work involved development of methods needed for the design of reactors. This included measurement and evaluation of nuclear data, development of reactor physics and thermal hydraulics methods, control system theories and equipment, sensors, materials, etc. In addition, organizations were assembled to work on supporting areas – health effects of nuclear radiation, chemistry, physics, etc.

II. Challenges Faced

In the fifty years since the start of the nuclear era, conditions in the U.S. have changed significantly. The support for nuclear power has waned and the support to nuclear R&D from the U.S. Congress has been reduced. The reasons for the decline in support for nuclear power have been well chronicled – the early optimism about the economics and operational advantage of nuclear power proved to be too hopeful. The major accidents at Three Mile Island and Chernobyl raised serious questions in the minds of the public and decision-makers on relying on nuclear power as a major energy option. The current plentiful availability of fossil energy (particularly natural gas) in the U.S. further reduced the basis for political support to nuclear R&D. The expectation for increased interest in nuclear power in the wake of the Kyoto accord and general concern for global warming has not materialized. In part, this is because of inherent uncertainties in global warming estimations; in addition, it is difficult to get public and political attention for very long-term problems. The upshot of all of these events is that support for nuclear R&D has declined dramatically.

As a natural consequence of reduced support, the missions of the multi-purpose national laboratories have become increasingly diffuse, as illustrated by the funding distribution shown in Figure 1. The earlier focus on high risk, high payoff R&D, which was the basic purpose in the formation of the National Laboratories, has now shifted toward nearer-term developmental activities. This near-term work has often proved to be unsuited to the existing cultures of the National Laboratories.

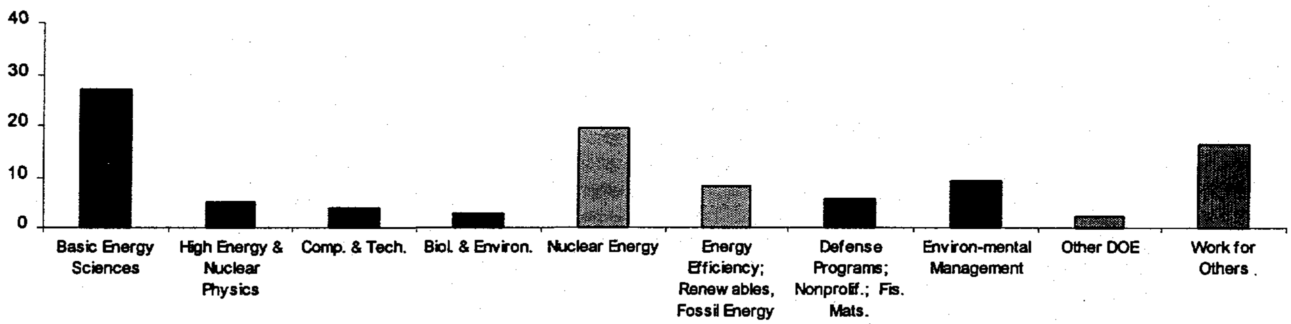

Figure 1. Argonne FY1999 Funding Levels (% of Lab Total)

Cost and mission considerations have resulted in the shutdown of numerous DOE research and test facilities including several at Argonne such as the EBR-II facility, the TREAT reactor, and several Zero Power Critical facilities. Several University reactors have also recently been permanently shutdown while others are facing difficulty in meeting operational expenses. Within the U.S. National Laboratory System the only test reactors still operating are the Advanced Test Reactor (ATR) at INEEL, the HIFR facility at ORNL, and the ACRR facility at SNL. It is ironic that the only reactor facility at Argonne, which in many ways was the birthplace of nuclear power, is a small TRIGA facility (the NRAD) at Argonne-West used for neutron radiography. The chance for the construction of a new nuclear test facility in the foreseeable future is slim at best. The Advanced Neutron Source (ANS) facility planned to be constructed at ORNL was cancelled because of projected cost overruns. The current plan is to construct the Spallation Neutron Source (SNS) at ORNL to provide the neutrons for science research;

this is an accelerator based neutron source. The story is alarmingly similar for the auxiliary nuclear facilities needed for R&D – hot cells, gloveboxes, etc.

The eroding infrastructure has been the subject of much discussion within the U.S. Department of Energy (USDOE). There is concern about safety and the costs of dismantlement and disposal of many of the contaminated facilities; replacement is generally far from decision makers' thoughts. Concomitant with the mission defocusing and infrastructure erosion is the major fact of reduced opportunities for research personnel. This leads to increasing frustration and reduced morale among the very bright people that generally populate the National Laboratories. In addition, it reduces the influx of new people that is so essential to adding new ideas and enthusiasm to any organization. The reduced opportunities in the nuclear field are well known; the result is reduced interest in Nuclear Engineering among students and reduced enrollment in the field. A majority of the Nuclear Engineering Departments in U.S. universities have had to merge with other engineering departments and have lost their independent identities.

All of the above add up to formidable challenges to the future maintenance of the "nuclear research centers" as defined by the IAEA. For those of us who believe in a nuclear future – one in which nuclear energy is a part of a national optimum mix of energy sources used to power the human enterprise for a long time to come – it is time to consider seriously the steps necessary to stabilize the situation and if possible turn it around soon. This workshop is certainly very timely in this regard.

What is needed is the development of relevant, sustainable long-term missions for the nuclear segments of the multi-purpose National Laboratories. These missions need to be defensible in public and political debates and thus supportable by the government. Such missions would provide stability to the enterprise, maintain expertise for the future, and aid in the transfer of expertise to new entrants to the field.

III. Current Programs

All of the U.S. Multipurpose National Laboratories now have broad-based R&D portfolios comprising nuclear technologies, basic sciences, environmental management, non-nuclear energy technology, national security, and industrial support components. The relative breakdown of these components varies from laboratory to laboratory. Even the defense laboratories (LANL, SNL, LLNL) have had major programs in the other areas included in their program portfolios. This is in keeping with the continued diffusion in the missions of most of laboratories. A feature of the science programs in the laboratories is the operation of large user facilities (e.g., the Advanced Photon Source at Argonne).

National Laboratories pursue the following R&D programs within the nuclear area:

- Nuclear waste management
- Spent fuel management
- Reactor Systems D&D
- Plant life extension
- Nuclear nonproliferation
- Isotope production
- Nuclear regulatory support
- Space nuclear applications
- Next generation nuclear plant concepts
- Nuclear fusion R&D
- Industrial support R&D

Some of Argonne's existing major programs in these and related areas are described briefly below. Argonne's current major initiatives for future work are shown in Figure 2.

1. Spent Fuel Management. Electrometallurgical technology is being utilized to condition spent fuel from the EBR-II reactor (sodium bonded metal fuel) in preparation for disposal. The technology has been demonstrated with a number of drive fuel elements

Science

- Rare Isotope Accelerator
- Strategic Computing
- Second Target at SNS
- Accelerated Protein Studies
- Fourth Generation Light Source
- Combinatorial Materials S&T
- Nanoscience

Environment

- Environmental Nuclear Technologies
- S&T for Environmental Stewardship
- Remote Treatment Facility at ANL-W
- Synchrotron Environmental Science

Energy

- Nuclear Technology R&D
- Transportation Technologies
- Ag-Biotech for Chemical Products

National Security

- Arms Control and Non-Proliferation Technologies

Fig 2. ANL Major Initiative Areas for FY2000

demonstrated with a number of drive fuel elements processed and several blanket elements processed to date. It appears that this method could be utilized for other fuels as well.

2. Reactor Systems D&D. The safe and cost effective deactivation and decommissioning (D&D) of nuclear reactor facilities that have reached their end-of-life is a very significant challenge in the nuclear system lifecycle. At Argonne a number of research and test reactors had been designed, constructed, and operated over the years. Essentially all of them have been shutdown now. Argonne has embarked on a program of developing, testing, and applying methods for safe and cost effective D&D. We have decommissioned four test reactor systems at the Argonne-East site, and have demonstrated a large number of advanced technologies for D&D. The methods and procedures developed are being utilized in the remaining D&D work at the Argonne facilities, throughout the USDOE complex, and elsewhere in the U.S. government (e.g., NASA). We also interact with the U.S. Nuclear Utilities to assist the owners in their D&D efforts. We developed and presented a significant training course in D&D to U.S. and international participants (this included an IAEA group in 1998).

3. Nuclear Nonproliferation. Like several other National Laboratories Argonne has a significant program on development of technologies and procedures to reduce the risks of widespread development of weapons of mass destruction and diffusion of associated technology. Argonne's main activities are in the areas of sensor systems development, proliferation analyses of various aspects of the nuclear fuel cycle, development and utilization of databases and analysis tools for nuclear materials control, and the Reduced Enrichment Research and Test Reactor (RERTR) program. The RERTR program has developed high density fuel with low enrichment uranium (<20% fissile enrichment) that can be used to enable research reactors to utilize LEU instead of HEU with little, if any, loss of performance. Over thirty-five reactors worldwide have been converted to date and several more are planned. Recently a joint program in this area has been established with Russia.

4. Isotope Production. Several National Laboratories (INEEL, ORNL, SNL) are involved in the production of radioisotopes for medical and other use. Argonne's

primary contribution this area is the development and demonstration of methods for the utilization of LEU targets to produce the Mo^{99} isotope.

5. Space Nuclear Applications. Several longer-term space missions (manned Mars landing, probes to the distant planets, etc.) will likely require nuclear fission devices for power and propulsion. Along with several other laboratories, Argonne has used its proven advanced nuclear reactor development capabilities to work on several concepts and on technologies to support this endeavor.

6. Nuclear Fusion. The core competencies developed in the course of the fission reactor programs (e.g., liquid metal technologies, materials science, activation evaluation, etc.) have been applied to the fusion power development program. Argonne scientists have worked in these areas collaboratively with U.S. and international colleagues for several decades in areas that include blanket and materials development.

7. Industrial Support. A number of Argonne's core competencies are being applied to help U.S. industry in various ways to become more efficient and cost competitive. Examples of technologies being applied are sensor systems, modeling capabilities, laser technologies, materials technologies, and environmental technologies.

8. Electrochemical Energy System Development. There is a major program at Argonne dedicated to the development and testing of electrochemical energy system (batteries and fuel cells) for use in the industrial and transportation sectors.

IV. Strengths and Limitations

The major strength of the U.S. National Laboratories in general, and Argonne in particular is the concentration of a large number of extremely capable technical people, many of whom have demonstrated skills in producing solutions to complex scientific and engineering problems. The expertise in laboratories such as Argonne is multidisciplinary. This is a major resource that can be used to tackle significant technical problems that face the nation, all of which require the utilization of multidisciplinary skills, working as a team. A second major strength of the laboratories is the availability of several billion dollars worth of capital equipment and instrumentation, much of which are one of a kind and cannot be reproduced without considerable expense. This combination of intellectual and physical assets coupled with the demonstrated capability of using them to solve large complex technical problems positions the laboratories well to tackle problems of national significance in the future.

The large and expensive infrastructure, however, is difficult to maintain and is expensive to keep in good operating condition. Since the major support for all the laboratories comes from the government, support from the annual budgeting process from the U.S. congress becomes a major issue. With declining public and political support for nuclear power, funding for nuclear infrastructure has been neither consistent nor totally adequate.

The other major complication with the National Laboratories is that it has proven to be quite difficult to make large changes in R&D directions because of the large inertia of the system. Attempts at privatization of pieces of the laboratory systems have not been very successful up to this point.

V. Interactions with Industry and Academia

The interactions of the nuclear energy R&D segment of the National Laboratories with the outside world are shaped by several factors. The considerable fossil energy sources available in the U.S. coupled with the disappointing economic performance of some of the nuclear power plants have reduced industry support for nuclear energy. The two major nuclear accidents in nuclear power plants have shaken public confidence in the technology. Finally the continuing debate of the high level waste repository at Yucca Mountain has created a negative impression. It is fair to say that overall public support is mixed, and the U.S. Congress does not fund much new R&D on nuclear systems.

An additional concern in the U.S. is created by the deregulation of the power industry. This is resulting in a massive re-evaluation of the economic bases for operating power plants and has been responsible for the premature shutdown of a number of nuclear power plants. Several other plants have been sold, some at incredibly low prices. While there are clearly conditions in the deregulated energy industry where nuclear plants would thrive, new construction will almost certainly be aimed at the more quickly constructed lower cost systems (such as natural gas burners). In this environment the interactions of the industry with the nuclear laboratories is limited to areas such as plant life extension, advanced sensors for monitoring and control, and D&D.

A consequence of the reduced activity in the nuclear field is reduced educational activity in the field in Universities. There are, thus, reduced interactions with academic institutions and reduced opportunities for graduating students to join the laboratories. As was mentioned earlier, this reduces the very necessary influx of new ideas and enthusiasm into the laboratories.

VI. Collaborations

The nuclear world has to be considered to be connected. Incidents in nuclear facilities in one part of the world are communicated to all areas instantaneously and affect the operations and thinking in real time as the incidents unfold. The recent criticality incident in Japan is a case in point. It is essential that international nuclear programs stay linked in order to benefit from individual experiences and in order to jointly anticipate potential problems and make the necessary moves to diffuse them. The other major reason to increase collaborations is that the cost of the development of a number of nuclear ventures and applications are very large and outside the capability of most nations to support individually. It would be prudent and cost-effective to share the development expense and risk amongst nations. It would also allow the inclusion of a large variety of viewpoints and ideas into these major developments.

There are several areas in which international collaborations are very appropriate. In several of these areas, some collaborations are already underway.

International Repositories for High Level Nuclear Waste

The question of repositories for the long-term and safe storage of high-level nuclear waste has moved to center stage in the nuclear scenario. Several countries (including the U.S.) have very large programs for repository development. These programs have involved identification, characterization, and environmental impact assessment of potential sites, construction of suitable waste repository structures, experimentation on migration of radionuclides, and addressing a host of legal and political questions. Most nations with small nuclear programs cannot afford the huge cost of repository development and their small needs do not justify such expenditures and effort. This has led to the development of the concept of international high-level waste repositories. There are several proposals for such repositories currently under consideration. The idea is not free from problems. Significant incentives have to be presented to the nation within which the repository is to be located. Consideration must be given to the expectation of long-term political and social stability of the host nation and their indefinite acceptance of strict safeguards regimes. Finally, the possibility has to be considered that international waste repositories could undermine viable national repository programs. In any case, this is an area of major significance to the sustainability of nuclear technology and is suitable for international collaboration.

Reactor Safety/Operations

This is an area in which significant collaborations are occurring already, some under IAEA sponsorship. Since the avoidance of nuclear accidents anywhere in the world is of paramount importance, every effort should be made to disseminate operations information and safety experiences to reactor operations worldwide.

Reactor Systems Decommissioning

As nuclear reactor systems age, there is a growing need for the development and utilization of methods for the safe and cost effective D&D of reactor facilities. This area represents a very large activity, estimated to cost about 1 trillion U.S. dollars worldwide over the next five decades. Several nations, including the U.S., have successfully decommissioned a number of reactor facilities – research, test and power systems. A set of technologies has been developed and continues to be developed to perform various facets of D&D efficiently. The experience and technologies developed can be utilized worldwide to complete the final phase of the first generation of reactor systems. It is our belief that this needs to be done safely and cost effectively to ensure that the next generations of nuclear systems will be possible.

Large Nuclear Applications

International collaborations are also very desirable for large nuclear projects. There has been long-term collaboration on the development of fusion energy, and this continues to this day, despite the recent decision by the U.S. to withdraw from the ITER project. The use of fission systems for space exploration and exploitation is an area that could provide exciting opportunities for collaboration in the 21st Century. The design of advanced nuclear power systems that incorporate features of inherent safety, proliferation resistance, reduced waste, and ease of decommissioning could be another area in which international collaborations could pay rich dividends.

There are a number of mechanisms by which such international collaborations could be effected. The IAEA provides a number of opportunities for such activities. There are also a number of bilateral and multilateral agreements through which collaborations are performed. In this regard, I would like to make special mention of the Nuclear Energy Research Initiative (NERI) project, recently started by the Nuclear Energy Branch of the USDOE to address the key issues affecting the future of nuclear energy. There is a strong impetus in that initiative to seek and utilize international collaboration.

VII. Other Considerations

By way of summary, a few significant points should be emphasized. First, we simply cannot afford to have another major nuclear accident anywhere in the world. Such an accident would cause a major loss of credibility from which it would be nearly impossible to recover. The recent criticality incident in JNC in Tokai Japan, while not a very major accident, certainly caused considerable consternation around the globe. A reactor accident of the Chernobyl scale could be disastrous. What is needed is an international repository of operational data and rapid dissemination of operational and safety information to all operators. Safety support should be made available to all reactor operations personnel.

Also, we cannot afford to have a nuclear proliferation incident triggered by a sub-national group. It will be essential to safeguard all nuclear materials and control the export of technologies, and the movement of experts to minimize the threat of terrorist groups acquiring and utilizing nuclear explosives. Again, strong international agreements on appropriate safeguards regimes and means of effectively implementing these regimes are needed. There is a fertile area of development and utilization of advanced sensor systems that are on-line and continuous and supported by modern signal processing and intelligent software in this area that needs to be considered. NRCs possess critical expertise for finding solutions in these areas.

Finally, the issues related to the safe and economic solution to the problems of the back end of the nuclear fuel cycle needs to be tackled effectively if there is to be any real hope of sustained utilization of the nuclear option worldwide.

VIII. Conclusion

Under the likely scenario in which public support for nuclear energy remains low and fossil fuels continue to be abundant and cheap, government supported nuclear research centers must adapt their missions to ensure that they tackle problems of current significance. It will be critical to be multidisciplinary, to generate economic value, and to apply nuclear competencies to current problems. Addressing problems in nuclear safety, D&D, nuclear waste management, nonproliferation, isotope production are a few examples of current needs in the nuclear arena. Argonne's original mission, to develop nuclear reactor technology, was a critical need for the U.S. in 1946. It would be wise to recognize that this mission was a special instance of a more general one – to apply unique human and physical capital to long term, high risk technology development in response to society's needs. International collaboration will enhance our collective chances for success as we move into the 21st century.