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U.S. Industry Opportunities for Advanced Nuclear Technology Development Phase III

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Changing the World's Energy Future

Matthew Kennedy, Robert Henry, PhD

Idaho National Laboratory

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Matthew Kennedy, Robert Henry, PhD

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Idaho National Laboratory
Idaho Falls, Idaho 83415

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16W070 83RD STREET • BURR RIDGE, ILLINOIS 60527
(877) FAUSKE1 OR (630) 323-8750 • FAX: (630) 986-5481 • E-MAIL: INFO@FAUSKE.COM

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1.0 BACKGROUND

This is the third phase of a work scope which has been focused on providing a framework for and preserving key experimental programs and experiences which are critical to the licensing basis of currently operating nuclear reactors or which could be used in the safety basis for the next generation of reactors. The first phase of this effort, documented in Reference 1, focused on compiling a list of key experimental programs through an international survey of reactor safety professionals working in licensing, design, and academia. The second phase in this effort, documented in Reference 2, focused on creating a searchable database framework in which to organize the results from the international survey and to perform detailed research on several key programs to provide the framework for how to categorize the references which could be located. The purpose of the third phase is to perform a high-level research effort on each experiment/experience and to determine if sufficient data, reports, and results have already been captured to consider the program archived for future generators of nuclear professionals. This was done through four specific tasks:

1. Organize the list of experimental programs at risk of being lost, from References 1 and 2, by the reactor coolant type the experimental results can be applied to. Each of the experimental programs will be grouped into one of five coolant type categories:

    a. Water (both light and heavy)

    b. Liquid metal (the specific coolant type is also to be identified)

    c. Gas (e.g., helium)

    d. Molten salts (the specific coolant type is also to be identified)

    e. Organic fluids

    Coolant characteristics have a huge influence on the design, operation, and licensing of commercial plants. From a practical viewpoint, these influences are so important that there is little commonality between the behaviors of the reactors under operational and possible accident conditions. Therefore, organizing the relevant information in the database based on coolant type would be beneficial when identifying relevant experimental data for specific reactor types.

2. Determine and document, in the Nuclear Archival Electronic Database (NAED), if experimental programs/experiences listed in Appendix B, "Updated List of Key Reactor Safety Experiments to be Archived," of Reference 1 have already been archived in some form of repository (e.g. OSTI). The aim of this effort is to narrow down the list of experimental programs/experiences requiring a significant research

and/or effort to locate records for archival. This requires a formal definition for the minimum requirements to consider a program/experience archived. All experimental programs/experiences in the NAED are then compared against this definition. If a program is considered archived, it will be documented within the NAED created in Reference 2. If not, it will be added to the list of programs/experiences that may require significant research and/or effort to locate records for archival.

3. Perform an assessment on one of the experimental programs that are found to be "not currently archived" as defined in Task 2. This will provide the framework to guide future archival activities for programs/experiences that are considered "not currently archived."

4. In addition to archival of experimental programs and experiences, it is also critical to capture firsthand experiences of the experts who worked on these programs/experiences through a series of interviews and oral histories. In this task a single program/experience will be selected, and existing oral histories will be researched, and captured in the database, to provide a framework for capturing future oral histories on other key programs/experiences.

2.0 Overview of Archival Effort

The goal of the overall archival effort, including its prior phases, is to characterize and enhance the archival status of experimental programs for the safety of light water cooled and advanced reactors by locating and documenting, to the extent possible, where the experimental test information for these programs has been archived. One of the needs identified by the Light Water Reactor Data Preservation Activity Team (further referenced as Team in the remainder of the document) from previous work scopes, Reference 2, was to organize the experimental programs based on coolant types to which the results pertain. From a practical viewpoint, the influences of the coolant material are so important that there is little commonality between the behaviors of the reactors under operational, and possible accident, conditions. Therefore, organizing the experimental programs, in the NAED, based on coolant type provides a structured approach for future data retrieval and provides a method to identify gaps in data archival for specific coolant types.

Once the coolant type was identified for each experimental program, the Team performed a broad search to ascertain the extent to which the experimental programs are currently archived. In previous efforts, documented in References 1 and 2, only a limited number of experimental programs were assessed. The previous efforts provided a framework for how to categorize the data and capture references which are at risk of being lost. Reference 1 provided the following structured approach (i.e., a ranking from A through H) for quantifying the varying levels of technical authenticity or data quality for each experiment.

<u>Data Quality Categories</u>

A) The original experimental data records or test reports that include tables or graphs (unprocessed or processed) of all the measured information for a given experiment

B) The experimental test report(s) that includes the processed data for those measurements judged to be the most important but does not satisfy the criterion in “A”

C) A program summary report that provides an overview of the test results

D) Peer reviewed papers for technical journals that have been published in the open literature by personnel directly associated with the experimental program

E) Peer reviewed papers for technical journals that have been published in the open literature by analysts that are using the experimental data

F) Industry reports that have been reviewed by a government agency as part of a licensing application

G) Technical papers that have not received peer reviews but were presented at group or specialist meetings

H) Slides used for a presentation of experimental results at a group or specialist meeting

With the structured approach for the data quality well defined, a definition needed to be developed for the reference source location which is where the reference or data is archived (e.g., OSTI). This definition is presented in Section 4.1 and the quality metrics for the location established. Several factors, including the commitment length to retain the document or data and the format of the document, are considered in this framework. The framework identifies seven categories (A through G) for reference source location quality (presented in Table 4-1). The combination of the data quality and the reference source location quality provides an 8x7 matrix (Table 4-2 and Table 4-3) to provide a definition of which programs the Team currently considers to be sufficiently archived and which experiments/experiences are at risk of data loss. Programs with high quality data (categories A through C) and source locations with suitable formats and commitments to retain data for long periods of time (A through B) are considered sufficiently archived. Programs which are outside these category ranges are identified and ranked in terms of the risk of potential data loss.

With this categorization matrix, a search of open literature sources was performed for each experiment/experience and a determination was made as to the currently archival status for all 129 experiments/experiences included in the list of key experiments (Reference 1). Section 4.3 provides a detailed result of each of the 129 experiments/experiences. This activity resulted in 47 experimental programs (36 percent) already considered sufficiently archived and at low risk of data loss. The activity also identified references for many of the programs which are not currently considered archived but are at medium (18 programs or 14 percent) or high risk (64 programs or 50 percent) of potential data loss. This insight provides the extent to how well an experiment/program has been archived in open literature sources and whether the data is currently retrievable. This allows the Team to prioritize key experiments which are not currently archived and require additional effort to retain data which may be available.

After performing the broad search/categorization, in depth search was performed on six experiment programs deemed to be critical, based on the Team's recommendation and discussion with GAIN, to determine if data has been archived in locations that were not included or identified in the open-source search. This included experiments/experiences which were performed at Department of Energy (DOE) Laboratories that could not be located, work that was done at universities or other private organizations that were not found during the broad search, and finally on an international program. The selected programs are as follows:

1. Argonne National Laboratory EBR-II Loss of Flow at Power Experiments

2. Argonne National Laboratory TREAT "R" Series 7 Pin Sodium Voiding Data

3. Argonne National Laboratory OPERA 7 Pin Sodium Voiding Data

4. Columbia University Down-flow Experiments

5. INER Integral System Test Facility (IIST) PWR Natural Circulation Experiments

6. Purdue University PANDA Experiments on BWR Passive Heat Removal

The work to this point (current scope and previous work scopes References 1 and 2), has focused on capturing reference reports and experimental data. The Team realized that capturing and archiving firsthand experiences from the individuals who were directly involved or supported the experiments/experiences can provide additional vital insight that cannot be obtained from a report. This effort looked to obtain current interviews or other firsthand accounts to understand how they are captured and to provide a framework for how future firsthand experiences can be archived.

3.0 Coolant Identification

In this first task, the Team worked to categorize the list of experimental programs from Reference 1 by the reactor coolant type that the experiments represent. Coolant characteristics are fundamental to the design, operation, and licensing of nuclear power plants. Therefore, organizing the list of experiments and adding a filter category to the NAED, developed in Reference 2, provides a structured and organized way to present the list of experiments so that future researchers, engineers, and licensing agencies can focus on the key reactor experiments/experiences for specific reactor/coolant types.

There are five main coolant types which have been historically used or proposed for reactor designs. Each experimental program was to be assigned to one of the five following coolant types:

1. Water, including both light and heavy water
2. Liquid metal
3. Gas
4. Molten salt
5. Organic fluids

Figure 3-1 provides a breakdown of the experiments, identified in Reference 1, based on the coolant type. The majority, nearly 80 percent, of the experiments pertain to water as the coolant or working fluid. This is not surprising as most reactors in operation around the world use some form of water for the coolant or moderator; therefore, historically the largest experimental focus has been on this coolant type. The remaining portion of the experiments used liquid sodium as a coolant (approximately 10 percent) and gas (carbon dioxide and air) as coolants (approximately 2 percent). While reviewing the list of experiments it was found that there are 12 experiments/experiences that are not coolant specific. These experiments focused mainly on fission product release and transport, neutronics experiments, and hydrogen combustion.

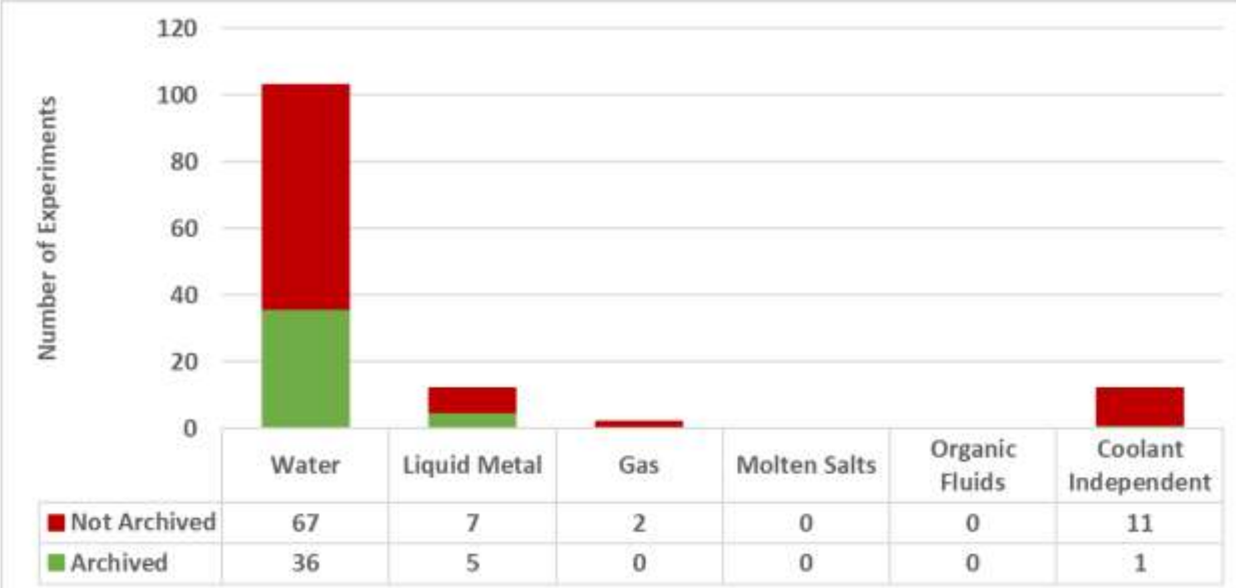

Figure 3-1   Breakdown of Experiments by Coolant Type

Figure 3-1 shows not only the breakdown of the experiments based on coolant type but also the number of these experiments that are considered archived versus not archived for each coolant type. Section 4.0 of this report provides the details on how the Team determined if an experimental program was considered archived. The results in Figure 3-1 show that approximately 40 percent of the water and liquid metal experiments are currently considered archived. This continues to highlight the gap that over half of the experimental programs which have been undertaken, regardless of the coolant type, are currently considered at risk of potential data loss.

4.0 Status of Experimental Archival

4.1 Definition of Archived

The noun "archive" relates to "a collection of historical documents or records providing information about a place, institution, or group of people" and the verb "archived" simply relates to placing or storing (something) in an archive. In the areas of nuclear reactor safety, the group of people (and organizations) of interest are those making decisions related to the design, construction, licensing, and operation of nuclear power plants. The collection of "historical documents or records" are the descriptions of the experiments or plant experiences and the collection of the experimental data that demonstrate specific behavioral characteristics relating to the design, construction, licensing, and operation of nuclear power plants. In simple terms, the desire is that important documents and experimental data is captured and can be retrieved for future reference.

As discussed in the following sub-sections, several organizations have been active in compiling and storing the information that has been gathered and reported over the decades for commercial power plants that have been designed and constructed by qualified vendors, licensed by a governmental agency, and operated by a utility within the boundaries of the license. Of particular interest to the Team for the data preservation activity has had numerous conference calls to address this most important issue. Of interest to all was the question: "What do we mean by archival records as this applies to nuclear reactor safety?" Through these discussions, the Team has seen this as requiring two essential parts.

The first is by creating a list of experiments/experiences deserving of archival status. Reference 1 developed the initial list of important experiments by surveying those teaching the fundamental concepts of nuclear fission, as well as those engaged in the design, licensing, and operation of nuclear power plants. After the survey was complete and a list of noteworthy experiments/experiences were determined for archival status, a method to categorize the quality of the data in a reference(s) was established. This identified that not all references on an experiment/experience provide the same level of data or peer reviews. This categorization placed a high emphasis on the original experimental unprocessed data and experimental summary reports that provide the test results. The list of data quality categories is recreated in the following subsection. Reference 1 concluded that eventually, copies of the materials for the identified experiments/experiences need to be found and placed into some archival process to ensure that the material is not lost through to the science of nuclear reactor safety.

<u>Data Quality Categories</u>

A) The original experimental data records or test reports that include tables or graphs (unprocessed or processed) of all the measured information for a given experiment

B) The experimental test report(s) that includes the processed data for those measurements judged to be the most important but does not satisfy the criterion in “A”

C) A program summary report that provides an overview of the test results

D) Peer reviewed papers for technical journals that have been published in the open literature by personnel directly associated with the experimental program

E) Peer reviewed papers for technical journals that have been published in the open literature by analysts that are using the experimental data

F) Industry reports that have been reviewed by a government agency as part of a licensing application

G) Technical papers that have not received peer reviews but were presented at group or specialist meetings

H) Slides used for a presentation of experimental results at a group or specialist meeting

The second essential facet for document archives, centers around data storage and accessibility. This focuses on where the existing archival sites are, how the sites are preserved, and whether or not the sites provide coverage of all the important experiments that were identified in the survey. A similar categorization, to the data quality, is required to answer these key questions and provide a definition for the second essential facet for data storage and accessibility. The Team created a definition for data storage and accessibility focused on two key metrics:

1. The commitment or expected length of time the document will be maintained as a record

2. The format/location of the archived document

The first metric is broken into three length categories: Long, estimated to be 50 years or longer, Medium, estimated to be between 10 and 50 years, and Short, less than 10 years. While this will still require a somewhat subjective determination, as the Team will be required to make a judgement on how long a report or data is likely to be archived in its current location. It is assumed that the range of the categories is sufficiently broad to capture the general intent of the archive location. Section 4.2 provides specific examples of archival policies of various organizations which help to inform the Team on how to categorize the data on this key metric.

The second key metric is on the format and/or location of the archived document. This is broken down into two categories, either suitable or unsuitable. A document is considered suitable if it is in a format and location that is easy to maintain and accessible for future generations. Ease of access implies that the individual has the appropriate permissions and clearances to access the data. Documents that are considered suitable are electronic records, pdfs, or other similar formats. These are relatively easy to maintain and access. Documents that are considered unsuitable are documents or data that are difficult to maintain and access. Examples of these types of documents can be hard copy records, micro-fiche files, or data records on legacy media (i.e., magnetic tapes, etc.). These are considered unsuitable because they are stored at a specific location limiting access and limiting the number of individuals with direct knowledge of their location. This can lead to data loss due to turnover with time, misplacement, discarded, degradation of specific media, or accidental destruction such as a fire.

Using these two metrics, Table 4-1 is created to categorize the source location for the reference documents and data. Table 4-1 identifies six categories to define the retrievability of the reference documents and data. Category A records are data or reports that are captured in a long-term repository and is in a suitable format or location for future researchers, engineers, and licensing professionals to access. Category F data is data that is not likely captured for the long term and is in a potential unsuitable format. The next section will review various organizations that archive various experimental information and grade them based on the Table 4-1 characterization.

Table 4-1 Definition of Source Location Characterization

		Format/Location	
		Suitable	Unsuitable
Archival Duration	Long (50+ yrs)	A	D
	Medium (10-50 yrs)	B	E
	Short (<10 yrs)	C	F

4.2 Organization Examples

4.2.1 Office of Scientific and Technical Information (OSTI)

Office of Scientific and Technical Information (OSTI) is part of the Office of Science which is within DOE. As defined by the *Energy Policy Act* PL 109–58, Section 982, OSTI is directed as follows: “The Secretary, through the Office of Scientific and Technical Information, shall maintain with the Department publicly available collections of scientific and technical information resulting from research, development, demonstration, and commercial applications activities supported by the Department.” To accomplish this, OSTI has begun to store electronic files, by scanning those technical reports and papers from numerous sources including:

- Technical reports published by DOE

- The Nuclear Regulatory Commission
- All of the reports published by the national nuclear laboratories (Argonne, Brookhaven, Hanford, Idaho, Lawrence Berkeley, Lawrence Livermore, Los Alamos, National Energy Technology, Oak Ridge, and Sandia)
- Open literature reports from nuclear vendors and utilities
- National and international conferences
- Scientific periodicals and recommended selected papers from informal meetings of experts

A huge effort is underway to bring the large amount of technical literature from decades past into the age of electronic files, but history of hard copy reports being thrown out or lost shows that this method of carrying forward the state-of-the-art of technical information is most certainly needed. This is already becoming one of the major sources for preserving the ever-growing technological areas. This is an example or data that would be considered archived for the long term and in a suitable format for easy access; therefore, references or data already archived by OSTI would be considered category A from Table 4-1.

4.2.2 American Nuclear Society

Another source of technical information is from the American Nuclear Society (ANS) which has continually promoted the documentation and exchange of such information since the first Annual Meeting in 1955. Information exchange has continued uninterrupted through two national society meetings per year, plus numerous topical meetings that center on specific subjects, and through peer reviewed publications in three journals: (1) Nuclear Science and Engineering, (2) Nuclear Technology, and (3) Fusion Science and Technology as well as two magazines (Nuclear News and Radwaste Solutions).

The archival structure for ANS is multifaceted to provide long term availability to retrieve the technical information that has been reported in the three technical journals and two magazines, mentioned previously and the Transactions for the ANS Winter and Summer Meetings as well as the historical and technical books published by the ANS. This structure is described below:

- ANS is in the process of scanning every issue of the technical journals, the two magazines and the ANS Transactions. This information is available to ANS members and subscribers (both searching and downloading) on the society website.
- A second archival level is achieved through a partnership between ANS and Clockss (a non-profit archive organization) that also provides an archival record of the ANS information. This duplication is in process.
- In addition, a third archival level has been constructed through a partnership between ANS and Taylor & Francis (the publisher of the three technical journals) where the publisher will maintain electronic copies of all the technical journal publications on the Taylor & Francis website in perpetuity.

- Lastly, each book published by the ANS has one printed copy and one PDF file transmitted to the Library of Congress to provide an archival record of each version published.

This is another example of an organization dedicated to long-term storage and maintaining references in accessible locations. Therefore, if a report or data is found to be a publication of the ANS it will be considered category A from Table 4-1.

4.2.3 Organization for Economic Co-operation and Development (OECD)

For 60 years, the Organization for Economic Co-operation and Development (OECD) has worked diligently to expand prosperity, equality, and opportunity in countries throughout the world. Within OECD is the Nuclear Energy Agency (NEA) that promotes, organizes, and documents the results of experimental programs that require the financial support of several countries. Some of these are the large-scale suppression pool containment tests performed in the Marviken test facility in Sweden, the Loss of Fluid Tests (LOFT) performed at the Idaho site which is now the Idaho National Laboratory (INL) and the fully integrated, in-reactor experiments performed in the Phebus facility (Cadarache Laboratory, France). With the large number of countries involved with one, or several of these large scale, integral experiments, the OECD has constructed their own archival system for maintaining access to the experimental data. The site https://www.oecd-nea.org/tools/ie/ provides a list of OECD archived files of important experiments.

This is another example of an organization dedicated to the long-term storage and maintaining references in accessible locations. Therefore, if a report or data is found to be a publication of the OECD it will be considered category A from Table 4-1.

4.2.4 Nuclear Regulatory Commission (NRC)

The U.S. Nuclear Regulatory Commission (NRC) was created as an independent agency in 1974 to ensure the safe use of radioactive materials for beneficial civilian purposes while protecting people and the environment. As a government agency and independent body, the NRC has an entire classification and disposition process for their records. The NRC Records Management Program is responsible for the development of policies and procedures for the creation and maintenance of records and information regardless of physical form or technology. Records maintained by the NRC are described in NUREG-0910 (Reference 16), which provides instructions for how long to retain records, and what to do with them afterwards.

As an example, Part 19 of NUREG-0910, Item 21 describes how scientific and technical reports from NRC research are handled. Paper records created before April 1, 2000 are considered permanent and are transferred to the National Archives and Records Administration (NARA) when they are 10 years old. Paper records used as a source for the creation of an Agencywide Documents Access and Management System (ADAMS) electronic record are destroyed two months after creation of the electronic record. ADAMS is the official recordkeeping system through which the NRC provides access to publicly available documents.

The previous example provides only a single case of the many types of records which the NRC handles. Therefore, based on this example, it can be concluded that the NRC mandate is in ensuring the safe use of radioactive materials for civilian purposes while protecting the people and the environment and not in creating a long-term data storage repository. NRC transfers many, if not all, of the files to the NARA which is dedicated to archiving documents for the long term. Therefore, documents or references found on ADAMS or other NRC pages may not be there into the future. By the previous definition this would indicate that references and data found on NRC sources would be categorized as B or C source locations. This is not to say that the reference was not transferred and maintained elsewhere in a long-term storage location but if the reference can only be found through the NRC it will be categorized according to the previous definition and will require additional effort to locate the document in a long-term repository location.

4.2.5 Electric Power Research Institute

Electric Power Research Institute (EPRI) has been involved with nuclear reactor experiments, as well as nuclear reactor experiences since 1972 and this has resulted in extensive documentation of EPRI sponsored experiments along with documentation for other larger experiments where there were multiple sponsoring parties. Studies performed with only EPRI sponsorship, are available to EPRI members.

There are numerous EPRI sponsored experiments that are directly related to nuclear safety. Some of those that were important in formulating the Severe Accident Management Guidelines (SAMGs) are:

Thompson, R.T. et al, 1988a. "Large-Scale Hydrogen Combustion Experiments, Volume I: Methodology and Results," EPRI NP-3878, Vol.I. (Reference 3)

Thompson, R.T. et al, 1988b. "Large-Scale Hydrogen Combustion Experiments, Volume II: Data Plots," EPRI NP-3878, Vol.II. (Reference 4)

This is another example of an organization dedicated to long-term storage and maintaining references in accessible locations. Therefore, if a report is found to be a publication of the EPRI it will be considered category A from Table 4-1.

4.3 Archived Experiment Status

Using the data quality and source location categories, presented in Section 4.1, a basis definition for references and experimental data is developed to determine if a program is considered archived. This basis definition is then used to evaluate each experiment/experience from Reference 1 and make a *yes* or *no* determination on whether an experimental program is considered archived. For an experiment/experience to be considered archived it must have at least one reference documented in the NAED, which is considered to be data quality categories A through C and have a source location category of A or B. Table 4-2 provides a matrix of whether a program is considered archived for all the possible data quality and source location combinations. Currently, of the 129 experiments/experiences from the list in Reference 1, 47 (36 percent) have at least one reference which is in the high-quality data in a suitable format and location to be considered archived. The remaining programs are considered not archived. That is not to say the data is lost at this point but indicates the Team was unable to locate reports or data which fell into the highest data quality category or captured in a sufficient format or location to be considered easily retrievable.

To provide additional insight on the data captured in the NAED, Table 4-3 was created to quantify the potential risk of data loss for each of the programs. This is the same matrix of data quality and source location combinations but ranks each program based on potential risk of being lost. If a program is already considered archived, the risk of being lost is low, since this contains the high-quality data in a long term and suitable format. Since the low-risk category is the same as programs already considered archived, 36 percent of the experiments/experiences fall into this category as shown in Figure 4-1. Figure 4-1 shows 14 percent of the programs were found to have data or reports on but did not contain all the information required to be considered in the highest three data categories or in a format that is sufficiently retrievable. These programs are considered medium risk of being lost since some data and analysis does currently exist and is retrievable, but additional work is required to either capture the document in a more suitable format or location or additional research is required to locate higher quality data sources. The remaining programs (50 percent) are considered high risk of being lost. If a program is considered high-risk, it could be for several reasons including, the data that has been found but is not located in a source dedicated to long term storage, additional research is required to find higher quality data references, or no information was found and data may already be lost.

Table 4-2 Archival Determination Decision Matrix

		Data Quality Category*							
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Data Archival Category	**A**	Yes	Yes	Yes	No	No	No	No	No
	B	Yes	Yes	Yes	No	No	No	No	No
	C	No	No	No	No	No	No	No	No
	D	No	No	No	No	No	No	No	No
	E	No	No	No	No	No	No	No	No
	F	No	No	No	No	No	No	No	No

*Data Quality categories are defined in Reference 1

Table 4-3 Risk Categorization for Data Being Lost

		Data Quality Category*							
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Data Archival Category	**A**	Low	Low	Low	Medium	Medium	Medium	High	High
	B	Low	Low	Low	Medium	Medium	Medium	High	High
	C	Medium	Medium	Medium	Medium	Medium	Medium	High	High
	D	Medium	Medium	Medium	Medium	Medium	Medium	High	High
	E	Medium	Medium	Medium	Medium	Medium	Medium	High	High
	F	High	High	High	High	High	High	High	High

*Data Quality categories are defined in Reference 1

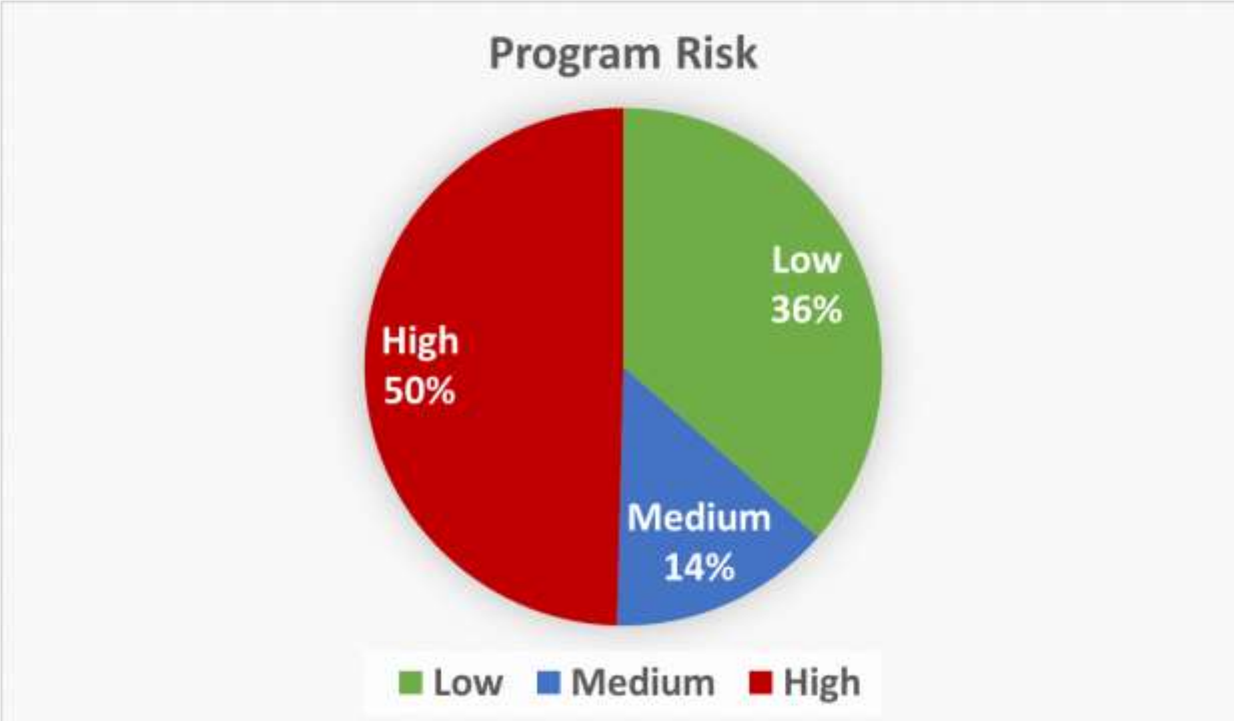

Figure 4-1 Results of Program Data Loss Risk

4.3.1 <u>Archived Experiments</u>

Table 4-4 provides a detailed view of the 47 programs to date which are considered archived along with their associated coolant types. In evaluating this list, most of the archived experimental programs were performed by national laboratories in the United States and are therefore archived by OSTI.

An example of the research effort that used the previously discussed methodology for determining if a program is archived is highlighted for the Southwest Experimental Fast Oxide Reactor (SEFOR) facility. This set of core experiments is directly relevant to advanced reactors that are cooled with liquid sodium. Most certainly a discussion of the SEFOR facility and its purpose, can be found in the general literature since the facility has been designated a "Nuclear Historic Landmark Site." The SEFOR performed highly transient experiments that produced a prompt critical state in the reactor core with the object being to determine if the Doppler Effect within the fuel would be sufficient to shut down the transient event.

Given this objective, the details of the reactor core in the test are crucial for the interpretation of the test results. Consequently, it is important that the references describing the test results and their interpretation are preserved. The reference below is already archived in the OSTI files and captured in the NAED. This reference contains a description of the experimental program and results discussion. It is categorized at data quality category C and is archived at OSTI indicating long term storage and easy access indicating source location category A. Given the combination of the data quality category and source location category, Table 4-2, indicates that the SEFOR program is considered archived.

Higinbotham, W.A., 1994. “Material Unaccounted for at the Southwest Experimental Fast Oxide Reactor: The SEFOR MUF,” Brookhaven National Laboratory Report SSN-94-26. (Reference 5)

In addition, there are five other references that were identified in the previous reference that are related to the interpretation of the SEFOR data. Two of these have been found in the OSTI listings and is given below.

Noble, L.D. and Wilkinson, C.D. 1968. “Final Specifications for the SEFOR Experimental Program,” AEC Research and Development Report, GEAP-5576. (Reference 17)

Freeman, D. D, 1973. “SEFOR Experimental Results and Applications to LMFBR’s,” General Electric Company, GEAP-13929. (Reference 18)

Three additional hard copy references were found and should also be archived to complete the preservation of important data. Currently, these are considered source location category F from Table 4-1. These references provide conference proceedings which presented the data and provided interpretation. Since these do not contain the original data or a full description of the experiments they are categorized as data quality category G but are still important to be captured for archival. These are:

B. Wolfe, 1967. “The SEFOR Project -- Its Significance and Progress,” Proceedings of the American Power Conference, Vol. XXIX, pp 189-201, Illinois Institute of Technology, Technology Center, Chicago, Ill. 1967. (Reference 6)

Broom K.M. and Mitchell S.L., 1970. “SEFOR: Southwest Experimental Fast Oxide Reactor,” Proceedings of a Symposium on Progress in Sodium-Cooled Fast Reactor Engineering, pp. 33-40, International Atomic Energy Agency meeting in Monaco, March 23-27. (Reference 7)

G. Billuris et al, 1967. “SEFOR Plant Design,” Proceedings of the Fast Reactor Topical National Meeting, American Nuclear Society (Northern California Section), San Francisco, CA, pp. 5-10 to 5-30, April 10-12. (Reference 8)

Table 4-4 Programs Already Considered Archived

High-level Phenomena	Experiment Description	Coolant Type
Nuclear Reactor Events & Accidents	SL-1	Light Water
Nuclear Reactor Events & Accidents	Fermi Unit 1	Sodium
Nuclear Reactor Events & Accidents	Diablo Canyon Unit 2 Mid-Loop Event 4/10/87	Light Water
Integral Experiments	LOFT	Light Water
Integral Experiments	Peach Bottom Turbine Trip, Delayed Scram Transient Test	Light Water
Integral Experiments	Phebus Experiments	Light Water
Integral Experiments	ANL - EBR-II Loss of Flow at Power Experiments	Sodium
Integral Experiments	SFD Severe Fuel Damage Experiments in the PBF (Power Burst Facility)	Light Water
Integral Experiments	FLHT (Full Length Heat Transfer Experiments)	Heavy Water
Integral Experiments	OSU AP1000 Experiments	Light Water
Integral Experiments	LOFT Semiscale Tests	Light Water
Integral Experiments	BWR Full Integral Simulation Tests	Light Water
Integral Experiments	ROSA-LSTF Experiments	Light Water
Integral Experiments	Seimans 4 Loop PWR PKL Test Facility	Light Water
Integral Experiments	CEA 3 Loop PWR BETHSY Test Facility	Light Water
Integral Experiments	FLECHT/SEASET Experiments	Light Water
Integral Experiments	ANL - TREAT "R" Series 7 Pin Sodium Voiding Data	Sodium
Integral Experiments	ANL - TREAT fuel behavior experiments	Sodium
Integral Experiments	ANL - Out-of-Reactor OPERA 7 PIN Sodium Voiding DATA	Sodium
Integral Experiments	Marviken Suppression Pool Experiments	Light Water
Integral Experiments	SNL IET Direct Containment Heating Experiments in the Surry Facility	Light Water
Integral Experiments	ANL IET Direct Containment Heating Experiments	Light Water
Separate Effects Core Experiments	SNL ACPR Prompt Burst Excursion Experiments	Sodium w/ carbide fuel
Separate Effects Core Experiments	SEFOR Experiments	Sodium
Separate Effects Core Experiments	CORA Core Damage Experiments - BWR	Light Water
Separate Effects Core Experiments	CORA Core Damage Experiments - PWR	Light Water
Separate Effects Core Experiments	SNL XR2-1 BWR Metallic Melt Relocation Experiments	Light Water
Separate Effects Core Experiments	Nuclear Fuel Behavior during Reactivity Initiated Accidents (NEA/CSNI)	Light Water
Separate Effects Core Experiments	ANL Whole Pin Furnace (WPF) Tests	Sodium
Separate Effects RCS Experiments	UPTF 2D-3D Experiments for a PWR Upper Plenum	Light Water
Separate Effects Containment Experiments	SNL Containment Experiments	Light Water
Separate Effects Containment Experiments	CVTR - Carolina-Virginia Tubular Reactor	Heavy Water
Separate Effects Containment Experiments	SNL 1/6 Scale Containment Ultimate Pressure Experiment	Light Water
Separate Effects Containment Experiments	Westinghouse Ice Condenser Experiments	Light Water
Separate Effects Containment Experiments	NUPEC 1/4 Scale of a 4 Loop PWER Containment	Light Water
Separate Effects Containment Experiments	NUPEC Large Scale Tests	Light Water
Separate Effects Fission Product Experiments	ORNL Fission Product Release Experiments	Light Water
Separate Effects Fission Product Experiments	CSE Fission Product Deposition by Sedimentation and Spray Experiments	Light Water
Separate Effects Fission Product Experiments	ACE & LACE Experiments	Light Water
Separate Effects Fission Product Experiments	ORNL Experiments on the Transport of Fission Products in Pressure Suppression Pools	Light Water
Two-Phase Critical Flow	GE Blowdown Tests	Light Water
Metallic Oxidation Kinetics	Baker-Just Zirconium Oxidation in steam	Light Water
Hydrogen Deflagration Experiments	EPRI NTS Experiments with a 70 m3 large vessel	Light Water
Hydrogen Detonation Experiments	BNL High Temperature Combustion - Hydrogen-Air-Steam Experiments	Coolant Independent
Quenching Experiments	FARO Large Scale Molten Core-Water Quenching Experiments	Light Water
Steam Expolsion Experiments	The SPERT-1 Test	Light Water
Steam Expolsion Experiments	KROTOS Experiments	Light Water
Steam Expolsion Experiments	JAERI ALPHA Experiments	Light Water
Steam Expolsion Experiments	JAERI COTELS Tests	Light Water
Steam Expolsion Experiments	KAERI TROI Tests	Light Water
Vapor Explosion Experiments	ANL Camel Loop Tests	Sodium
Molten Pool Experiments	CEA - BALI Experiment of molten fuel circulating in the lower head	Light Water
Molten Pool Experiments	MCCI Project (OECD - ANL)	Light Water
Molten Pool Experiments	RASPLAV Experiments	Light Water
Molten Pool Experiments	IVO-COPO Experiments	Light Water
In-Vessel Retention	UCSB ULPU and ULPU-2000 Experiments	Light Water

4.3.2 Experiments at Medium Data Loss Risk

Table 4-5 provides a list of experiments that are considered at medium risk of data loss. These are programs that contain some references with experimental data which often is not considered to contain all the data on the experimental program leading to the data quality category being D through E. For the majority of these programs, a peer review paper or journal focusing on a specific aspect of the experiments is provided. Theses references do not provide sufficient detail on the entire program to be considered archived. Therefore, additional work is suggested on these programs to locate program summary reports for the specific programs and include them in the NAED.

Additionally, there are several programs or experiences where there is considerable data and references recorded in a suitable format to be considered archived. The reason these are classified as medium risk of data loss is because there is so much data the Team has not been able to decipher the few key references which should be archived and documented in the NAED. One such example are the events at Three Mile Island. There are countless books, reports, and journal articles documenting these events, but the Team has not been able to sift through all the documents to find the references for inclusion in the NAED. Therefore, they are marked as medium risk to indicate additional work is required to locate the specific references, but the data does likely exist in an archived location.

Table 4-5 Programs Considered at Medium Risk of Potential Data Loss

High-level Phenomena	Experiment Description	Coolant Type
Nuclear Reactor Events & Accidents	Three Mile Island Unit 2	Light Water
Nuclear Reactor Events & Accidents	Fukushima Units 1, 2, and 3	Light Water
Integral Experiments	ROSA-LSTF Experiments	Light Water
Integral Experiments	Seimans 4 Loop PWR PKL Test Facility	Light Water
Integral Experiments	Hitachi BWR Two-Bundle Loop Experiments	Light Water
Integral Experiments	Marviken Suppression Pool Experiments	Light Water
Integral Experiments	HDR RCS Blowdown Experiments	Light Water
Separate Effects Core Experiments	CORA Core Damage Experiments - PWR	Light Water
Separate Effects Core Experiments	Measured Characteristics of Xenon-Induced Spatial Oscillations in H.B. Robinson Unit 2	Light Water
Separate Effects Core Experiments	Active Direct Measurement of Residual Fissile Content in Spent Fuel Assebmlies (EPRI)	Light Water
Separate Effects Core Experiments	Evaulation of Mass Spectrometric and Radiochemical Analyses of Yankee Core I Spent Fuel	Light Water
Two-Phase Critical Flow	Marviken Critical Flow Tests	Light Water
Metallic Oxidation Kinetics	Urbanik-Heidrick Zircaloy02 and Zircaloy-4 Oxidation in steam	Light Water
Vapor Explosion Experiments	CORECT-II Sodium - UO2 Experiments	Sodium
Molten Pool Experiments	PSI CORVIS Experiments	Light Water
Molten Pool Experiments	COMET Experiments	Light Water
Molten Pool Experiments	DISCO Tests	Light Water
In-Vessel Retention	SULTAN Experiments	Light Water

4.3.3 Experiments at High Data Loss Risk

Table 4-6 provides a detailed view of the programs to date which are not considered archived and are at high risk of data loss. As previously mentioned, just because a program is considered in this category does not mean that data is already lost but rather that the Team has been unable to locate a reference with the combination of sufficient, high-quality data and in a suitable format and location for retrieval.

Upon reviewing Table 4-6, many of the experiments that are most likely to be at high risk of data loss were those performed in the early days of the nuclear industry. These mainly focused on the nature of reactors that could be used for generating electricity. An example to highlight one of the earliest sets of reactor test conditions which are considered at high risk for data loss are those from the BORAX program. An initial search yielded very few open-source records which could be found to document the early BORAX program. Many of the references found include brief descriptions of the BORAX program and how it was a precursor to follow-on, experimental programs. Two such reference included in OSTI's records are:

> Boing, L.E., Wimunc, E.A., and Whittington, G. A., 1990. "Design-development and Operation of the Experimental Boiling-Water Reactor (EBWR) Facility, 1955-1967." (Reference 9)

> Deitrich, J. R., 1955. "Experimental Investigation of the Self-Limitation of Power During Reactivity Transients in a Subcooled Water-Moderated Reactor – BORAX-1 Experiments, 1954," AECD-3668. (Reference 10)

These references provide an overview of only a portion of the BORAX experimental program and describe the testing performed with the BORAX-1 reactor. Therefore, as the entire experimental program is not documented in sufficient detail this program is considered not to be sufficiently archived.

In addition to the references on the program, an additional open-source reference was found that provides a handwritten account by a member of the crew that performed the destructive testing that was part of the BORAX program. The following reference is captured in the NAED. Section 6.0 describes the importance of capturing first-hand accounts in addition to data and program summary reports.

> Haroldsen, R., 2008. "THE STORY OF THE BORAX NUCLEAR REACTOR And the EBR-I Meltdown; How It All Came To Be, Destructive Test of the First Borax, Lighting of Arco with Atomic Power, The Russian Connection." (Reference 11)

In addition, to the BORAX example, since most of the experimental studies for sodium cooled reactors occurred in the 60s, 70s, 80s, and 90s, there is some concern that some of the information could be lost. Because of the scale of the EBR II experiment and the impressive tests that were performed to illustrate the natural behavior of the sodium cooled reactor that would shut down the fission reaction naturally should the reactor be exposed to Station Blackout conditions; it is highly likely that these Argonne National Laboratory (ANL) reports are already in the OSTI archives. Given the scale of the program it has been difficult to track down a small number of specific references for inclusion in the NAED. So, while the data may be archived it is considered in this category of high risk since a small number of specific references to provide the detailed program overview need to be researched further. In addition to the program summary reports and data, the smaller scale test information could be lost which could be critical to maintaining archived data. Several references of these smaller scale tests reside as hardcopies in which the Team has found. These could be candidates, as part of a future scope, to determine if they are part of those that should be included in the OSTI archives. If they are already in the OSTI archives, no additional work is needed on these. If one, or both, are not in the OSTI archives, they will be recommended as information that needs to be added to the OSTI list of important information to be preserved.

Table 4-6 Programs Considered at High Risk of Potential Data Loss

High-level Phenomena	Experiment Description	Coolant Type
Nuclear Reactor Events & Accidents	Chernobyl Unit 4	Light Water
Nuclear Reactor Events & Accidents	Lucens	Carbon Dioxide
Nuclear Reactor Events & Accidents	Windscale	Air
Nuclear Reactor Events & Accidents	Santa Susana Sodium Reactor	Sodium
Nuclear Reactor Events & Accidents	NRX	Light Water
Nuclear Reactor Events & Accidents	LaSalle Unit 2 Dual Recirculation Pump Trip 3/9/88	Light Water
Nuclear Reactor Events & Accidents	Laguna Verde Power Oscillation Trip 1/24/95	Light Water
Nuclear Reactor Events & Accidents	Ringhals 1 Core Stability Benchmarks	Light Water
Integral Experiments	OSU AP600 Experiments	Light Water
Integral Experiments	CEA 3 Loop PWR BETHSY Test Facility	Light Water
Integral Experiments	ISPRA LOBI Experiments	Light Water
Separate Effects Core Experiments	Godiva Experiment	Coolant Independent
Separate Effects Core Experiments	CORA Core Damage Experiments - BWR	Light Water
Separate Effects Core Experiments	FZK QUENCH Experiments	Light Water
Separate Effects Core Experiments	**Columbia University Downflow Experiments**	**Light Water**
Separate Effects Core Experiments	Axial Xenon Transient Tests in Ginna	Light water
Separate Effects Core Experiments	International Handbook of Evaulated Criticality Safety Benchmark Experiments (NEA/CSNI	Coolant Independent
Separate Effects RCS Experiments	EPRI - Westinghouse SF6 Experiments on PWR Natural Circulation	Light Water
Separate Effects RCS Experiments	**IIST PWR Natural Circulation Experiments**	**Light Water**
Separate Effects Containment Experiments	BMC - Battelle Model Containment Experiments	Light Water
Separate Effects Containment Experiments	CSTF - Containment System Test Facility Experiments	Light Water
Separate Effects Containment Experiments	**PSI ETH - PANDA Experiments on BWR Passive Heat Removal**	**Light Water**
Separate Effects Containment Experiments	ANL MACE (MCCI) Experiments	Light Water
Separate Effects Containment Experiments	KfK BETA (MCCI) Experiments	Light Water
Separate Effects Containment Experiments	Westinghouse AP600 PCCS Experiments	Light Water
Separate Effects Containment Experiments	University of Wisconsin AP600 Experiments	Light Water
Separate Effects Containment Experiments	JAERI Containment Spray Tests	Light Water
Separate Effects Fission Product Experiments	ABCOVE Aerosol Desposition Experiments	Light Water
Separate Effects Fission Product Experiments	Marviken Fission Product Release and Deposition Experiments	Light Water
Separate Effects Fission Product Experiments	ANL Experiments on Fission Product Revaporization	Light Water
Separate Effects Fission Product Experiments	JAERI WIND Experiments on Fission Product Deposition, Revaporation and Resuspension	Light Water
Separate Effects Fission Product Experiments	RadioIodine Test Facility	Coolant Independent
Separate Effects Fission Product Experiments	Iodine Chemistry and Behavior Research	Coolant Independent
Separate Effects Fission Product Experiments	AECL Whiteshell Iodine Chemistry and Behavior Research	Coolant Independent
Two-Phase Jet Impingement	Marviken Large Scale Impingement Tests	Light Water
Metallic Oxidation Kinetics	Baker-Limatainen Aluminum Oxidation in steam	Light Water
Hydrogen Deflagration Experiments	SNL Experiments	Coolant Independent
Hydrogen Deflagration Experiments	SNL Inerting Experiments	Coolant Independent
Hydrogen Deflagration Experiments	VGEX Experiments	Coolant Independent
Hydrogen Deflagration Experiments	AECL Whiteshell Experiments on Non-Uniform Mixtures	Light Water
Hydrogen Deflagration Experiments	AECL Interconnected Vessel Tests	Coolant Independent
Hydrogen Detonation Experiments	SNL FLAME Facility Experiments	Coolant Independent
Hydrogen Detonation Experiments	HUCTA - Hydrogen Unconfined Combustion Tests	Coolant Independent
Steam Expolsion Experiments	The BORAX-1 Test	Light Water
Steam Expolsion Experiments	SNL FITS A and FITS B Experiments	Light Water
Steam Expolsion Experiments	ISPRA Molten Salt - Water Explosion Experiments	Light water
Steam Expolsion Experiments	KROTOS Experiments	Light Water
Steam Expolsion Experiments	JAERI COTELS Tests	Light Water
Steam Expolsion Experiments	KAERI TROI Tests	Light Water
Steam Expolsion Experiments	ANL ZREX Experiments	Light Water
Steam Expolsion Experiments	KTH - PULiMS Experiments	Light Water
Steam Expolsion Experiments	SNL Large Scale Molten Aluminum-Water Experiments	Light Water
Steam Expolsion Experiments	University of Wisconsin Aluminum-Water Shock Tube Experiments	Light Water
Vapor Explosion Experiments	ANL Out-of-Reactor Na Injected into Molten UO2	Sodium
Molten Pool Experiments	MASCA Experiments	Light Water
Molten Pool Experiments	ECOKATS Tests	Light Water
Molten Pool Experiments	SNL Swiss Tests	Light Water
In-Vessel Retention	ACOPO and Mini-ACOPO Experiments	Light Water
In-Vessel Retention	Penn State Experiments	Light Water
In-Vessel Retention	SNL CYBL Facility Experiment	Light Water
RCS and RPV Failure Mechanisms	Stuttgart PWR Hot Leg Creep Rupture Failure Experiments	Light Water
RCS and RPV Failure Mechanisms	SNL Lower Head Creep Failure Tests	Light Water
RCS and RPV Failure Mechanisms	KTH EC-FOREVER Experiments	Light Water
RCS and RPV Failure Mechanisms	EPRI Lower Head Penetration Experiments	Light Water

4.4 Lack of Original Experimental Data

During the research effort, discussed in the previous sections, there was not a single instance of category A, original experimental data, which could be located. While data in this category is not required for a program to be considered archived, it is concerning should the original data need to be consulted for future design or licensing applications. The following sub-sections describe a few such instances of the efforts by the Team to locate the original data records.

4.4.1 LOFT

The Loss of Fluid Test (LOFT) experimental program was a research program originally established by NRC, in which several configurations of loss-of-coolant accident (LOCA) with large break tests and intermediate break tests, were conducted at the (INL) between 1978 and 1982. As was common at the time, the experimental data was recorded on 6-inch magnetic tape. The Team recalls that the NRC maintained the ability to read these magnetic tapes for some time after the experimental program was concluded. At some point, in the decades that followed, the decision was made to no longer maintain the machine that could read these 6-inch magnetic tapes. What was not clear is what became of the 6-inch magnetic tapes and if the data was stored on a different media prior to the retirement of the machine which could read the tapes.

As part of the effort to determine if the LOFT experiments were archived, which concluded they are through various experimental summary reports, the Team dug a little deeper to see if the original data records could be found. After inquiring with the INL library, the Team was informed that they do not have a specific location where the experimental tapes may reside, if they still exist. It was mentioned that there is a “room full” of tapes and other media containing bar codes but with no other clear identifying marks as to what could be contained on the tapes. There also does not appear to be any way to read these legacy data storage media; therefore, it would require a considerable undertaking to potentially identify what data still exists on these tapes. It would appear at this point, without a significant dedicated effort that the original experimental records can be considered lost due to the ever-changing technology.

4.4.2 Westinghouse Ice Condenser Experiments

A second example of attempting to track down the original data records is with the Westinghouse Ice Condenser experiments performed at the Waltz Mill facility. A non-proprietary summary report, containing redactions, of these experiments is provided on the NRC website, link provided in the NAED. There is a disclaimer at the beginning of the report which directs an individual to contact Westinghouse Electric Corporation should it become necessary to release the full version of the document under specific arrangements to protect intellectual property.

As is likely the case, with all non-government organizations, the data included in these reports is proprietary and is archived according to the specific quality assurance and contract requirements for the program. As was previously mentioned the retention of the original experimental data would have been a quality requirement of the program or a contractual requirement. Given the age of the data, a printed hard copy of the record data would be placed into long term storage, likely in a salt mine or vault. The challenge with recovering these records is locating the records in long term storage as it is not uncommon for the organizational aspect of the archiving process to evolve with time. Similar to the LOFT example, these original data records can be very difficult to locate. Therefore, if needed by designers or licensing professionals in the future, the program summary report, which is considered archived, is the best source of data on this experimental program.

4.4.3 Fukushima

The two previous examples focused on experimental programs from many decades ago, so the Team additionally considered a more recent example. The research and support efforts surrounding the events at the Fukushima Daiichi reactors provided a likely candidate. While the original data records which do exist from those events are likely maintained by the utility operator, the focus of this effort was to track down the references and support provided by the U.S. national laboratories. The team worked with INL, which lead the response and support.

Based on discussions with INL, it would appear, there are several efforts underway to archive data associated with this effort. The following three links were shared with the Team:

1. DOE Robotic and Remote Systems Assistance to the Government of Japan, INL/EXT-13-28233; https://doi.org/10.2172/1076533
2. https://lwrs.inl.gov/SitePages/GroupedReports.aspx?ReportCategory=Reactor%20Safety%20Technologies
3. Fukushima Daiichi Information Repository FY13 Status INL/EXT-13-30234; https://doi.org/10.2172/1115615

The first and second links provide access to publicly available reports that document research and support that the national laboratories provided surrounding the events or lessons learned from the events at Fukushima Daiichi. The third link is to an INL report outlining how information related to Fukushima Daiichi was to be archived in a repository. This provides an indication to the Team that the data is currently either archived or partially archived. At the time of the writing of this report the information is located on servers at INL but it was not clear if efforts were continuing or what the retention policies of the program related to long term archival.

5.0 Extended Research on Select Programs

Upon completion of the high-level determination if a program was considered archived the Team performed extended research on a few select programs that were not considered archived. These focused on

1. work performed at U.S. national laboratories which could not be located as already archived within OSTI,

2. programs or experiments performed at universities or non-government organizations in the U.S., and

3. programs or experiments performed internationally that might be harder to locate.

Several programs or experiments which were performed at U.S. national laboratories which could not easily be located included:

- EBR-II Loss of Flow at Power Experiments
- TREAT "R" Series 7 Pin Sodium Voiding Data
- Treat Fuel Behavior Experiments
- Out-of-Reactor OPERA 7 Pin Sodium Voiding DATA

During the extended research, two findings were uncovered that are worth noting on the aforementioned programs. The first is that in addition to the references made publicly available by OSTI, there is a separate database which is offered to the DOE community and approved researchers that is not publicly available. This non-publicly available database is known as the Science Research Connection (https://www.osti.gov/src/login) and contains research information integrated from various OSTI databases, including both unclassified/unlimited and statutorily controlled information. Access to the site is free but requires either IP authentication and/or registration. Access is limited to DOE Federal or DOE contract employees who require access in support of an ongoing DOE contract effort.

The second item uncovered is that the Gateway for Accelerated Innovation in Nuclear (GAIN) has already gathered and generated databases in support of the advanced nuclear industry. The GAIN Legacy Document Project was initiated in 2016, after the advanced nuclear industry identified the access to legacy documents was one of the top four, cross-cutting needs critical to the commercialization of advanced reactor technologies. The GAIN website (https://gain.inl.gov/SitePages/Databases.aspx) currently contains databases or is in the process of collecting data for the creation of a database for the TREAT, EBR-II, and Out-of-Pile experimental programs.

Upon review it was found that many of the experimental programs previously outlined, which were initially considered as not archived, have been extensively archived through various databases to support the commercialization of advanced reactor technologies. As outlined in Section 7.0 this inconsistency should be resolved for programs which are extensively archived through separate databases which are outside the open literature sources considered in this effort.

In addition to the programs previously outlined, several other experiments that are relevant to advanced reactors are those related to overheating of a fast reactor core that is cooled by liquid sodium. These experiments were performed to support the safety evaluations that were being carried out for the Fast Flux Test Facility (FFTF) and the Clinch River Breeder Reactor (CRBR). Of particular interest for the associated behaviors were the superheat needed to initiate boiling of the sodium coolant and the voiding rate that would occur given a specific power level in the core. Important experiments and discussions of the experimental results can be found in the following references and some of these could be vulnerable to changes in the technology used to store information. These may already be in the OSTI archives, but this should be verified, as part of future scope, to assure that these experimental studies are not lost.

R.E. Holtz, H.K. Fauske and D.T. Eggen, 1971. "The Prediction of Incipient—Boiling Superheats in Liquid-Metal-Cooled Reactor System," Nucl . Eng. Des. 16, 4~ 285—293. (Reference 12)

H.K. Fauske. "Nucleation of Liquid Sodium in Fast Reactor," J. Reactor Technology 15 (4) (Winter 1972—1973). (Reference 13)

R.E. Henry, et al, 1974. "Sodium Expulsion Tests for the Seven Pin Geometry," Proceedings of the Fast Reactor Safety Meeting, Beverly Hills, CA., Vol.3, pp 1188-1201. (Reference 14)

M.A.Grolmes, et al, 1974. "R-Series Loss-of-flow Safety Experiment in TREAT," Proceedings of the Fast Reactor Safety Meeting, Beverly Hills, CA., Vol.1, pp 279-302. (Reference 15)

In addition to the experiments performed for commercial nuclear power plants, there were several experimental programs that explored the onset of flow reversal for water reactors that were designed with downflow through the reactor core, should the reactor be at power and experience a loss of flow transient. Columbia University had facilities that could be used for these studies. For such a transient, the decreasing downflow would eventually transition into up-flow that is driven by the buoyancy of hotter water in the core. Depending on the power level in the reactor core, the flow stagnation that occurs as part of the transient may experience dryout and overheating of the reactor fuel. The purpose of the experiments was to examine the conditions where dryout and overheating would be sufficient to cause damage to the reactor core. Due to the specific conditions of interest for downflow, these experiments should be considered as candidates for archiving simply because there are not many experiments that have been carried out for the high velocity downflows examined in the Columbia tests. It appears that some of the reports are listed in the OSTI files. This should be examined to ensure that the test data has been captured.

Finally, the last data category for the extended research focused on programs or experiments that were performed outside of the U.S. that may not be easy to locate. As mentioned in Section 4.2.3, the NEA within OECD is dedicated to promoting, organizing, and maintaining documents and results of experimental programs that required the financial support of several countries. A search of the OECD archive listing shows that the following programs are considered archived (a portion of the references which could be located are documented in the NAED):

- Fully Integral Experiments (Core, RCS, Containment, Fission Products)
- LOFT – Loss of Fluid Tests
- Phebus Experiments
- Partially Integrated Experiments
- LOFT Semiscale Tests
- BWR Full Integral Simulation Tests (FIST)
- ROSA-LSTF Experiments
- Siemens 4 Loop PWR PKL Test Facility
- Hitachi BWR Two-Bundle Loop Experiments
- CEA 3 Loop PWR BETHSY Test Facility
- Marviken Suppression Pool Containment Experiment
- SEPARATE EFFECTS CORE EXPERIMENTS
- BWR CORA Core Damage Experiments
- PWR CORA Core Damage Experiments
- SEPARATE EFFECTS RCS EXPERIMENTS
- UPTF 2D-3D Experiments for a PWR Upper Plenum
- SEPARATE EFFECTS FISSION PRODUCT EXPERIMENTS
- Marviken Fission Product Release and Deposition Experiments
- SEPARATE EFFECTS PHENOMENOLOGICAL EXPERIMENTS
- Marviken Critical Flow Tests
- Marviken Large Scale Impingement Tests
- Steam Explosion Experiments
- KROTOS Experiments
- JAERI ALPHA Experiments
- JAERI COTELS Tests
- KAERI TROI Tests
- Molten Pool Experiments
- RASPLAV Experiments
- Possible RCS and RPV Failure Mechanisms
- SNL Lower Head Creep Failure Tests

The NAED does not contain a full listing of the references for the international experiments list previously as the Team did not have access to review them in order to categorize them against archival definition defined in Section 4.0. Including the key references in the NAED, should be undertaken in a future project scope.

6.0 Firsthand Accounts

In addition to the experimental data and program summary reports, firsthand accounts from the experimentalists or operators who witnessed and/or participated in these experiences provides invaluable insight to the mindset, economic, and political contexts under which these experimental programs were undertaken. This additional insight beyond the data and technical descriptions can provide context into why certain experiments were performed, why experiments were setup in a specific way, and can capture thoughts and insights from the experimentalists themselves.

Two such examples the Team investigated were the firsthand accounts for the BORAX test program and interviews from the operators from Three Mile Island. As was previously mentioned, in Section 4.3.3, the Team uncovered a reference, Reference 11, for the BORAX program which is a firsthand account written by Ray Haroldsen, who helped to construct and operate the BORAX III reactor which first supplied electricity to the city of Arco, Idaho. As Ray, points out in the preface to the story, technical reports written 50 years ago still exist in technical libraries and while they provide the cold, hard, factual conclusions they make no mention of the human drama that was an integral part of the events. In the story, he mentions that the BORAX reactor was developed under the political climate of the Cold War and the desire for the United States to defend our honor and demonstrate our superiority in nuclear reactor technology for civilian purposes.

He goes on to mention that the BORAX reactor program was undertaken due to a criticality accident which had occurred at ANL due to operator error. The criticality experiment was at extremely low power, but the error caused the critical assembly to go prompt critical resulting in a steam explosion within the assembly. As the account goes on the staff marveled that the incident was relatively mild compared to previous assumptions that a water moderated reactor would be very unstable if allowed to go into a boiling state. This example highlights that, at the time, it was believed that a boiling water reactor was nearly impossible due to the anticipated instability of the rapid boiling that would ensue. However, an unrelated event showed that it could potentially be possible leading to the BORAX program and ultimately to the Boiling Water Reactors in operation today. The ability to connect the various events and the mindsets, at the time, provide additional context to the experiment that are not likely documented in technical program summary reports.

Similarly, to the BORAX example, firsthand accounts of the events at Three Mile Island provide an opportunity to document accounts of operators and support personnel who were actively involved. At 4 am on March 28th, 1979, Unit 2 of the twin units located on Three Mile Island, experienced a loss-of-feedwater event that eventually resulted in a loss of cooling water inventory from the reactor vessel that was sufficient to cause melting of the reactor core. Needless to say, this caused panic among those living around Harrisburg, Pennsylvania. This panic was further increased by media reporting that sometimes was thoughtful, but mostly written by people who had no knowledge of what they were writing about. Most importantly, reactor vendor and utility managers, along with regulatory personnel, had to cooldown and stabilize a reactor that had been damaged to an unknown extent. Furthermore, they had to address the consequences of the accident which included large amounts of hydrogen generation and the release of radioactive fission products into the containment building. It is important to document their thoughts and actions that were taken during the lengthy process of bringing the damaged plant to a safe and stable shut down status.

Harold R. Denton was Director of the Office of Nuclear Reactor Regulation for the NRC. Once the accident occurred, he took charge of government activities which included the public health and safety for those within a radius of several miles of the Three Mile Island. Mr. Denton has written a book ("Three Mile Island and Beyond: Memories of a Life in Nuclear Safety") for the ANS that documents his memories of the tasks that had to be undertaken and how this was accomplished. Since this is an ANS book, it has been archived in the Library of Congress (Control Number 2021931982) as discussed previously. This provides one valuable source of information regarding the difficult decisions and considerations that must be addressed during a crisis of this nature.

The NRC also conducted person-to-person interviews with personnel directly connected with certain aspects of the recovery from the accident and the de-fueling of the damaged reactor. These are another source for capturing knowledge relevant to dealing with a commercial nuclear that is undergoing an event that is outside of the licensing basis of the reactor design. These interviews should be included in the relevant information to be archived.

7.0 A Possible Next Step

This broad scope study has focused on the creation of a definition for what it means for an experiment/experience to be archived and applying that definition through a search of open literature sources to determine if certain programs can already be considered archived. This was done by searching open literature sources and several DOE-specific, reference databases to determine if key references are captured in a suitable format for the foreseeable future. This will allow such references to continue to be used by licensing and design professionals for nuclear power plants for many years to come.

The current effort has also shown that there are several gaps on critical programs that still require additional effort to determine if data has already been archived or irretrievably lost. The following outlines several recommended next steps to close the gaps found during this effort.

1. Upon a more extensive research effort in the current scope of work, it was found that many of the experimental programs that were originally considered at risk have been sufficiently archived through various databases to support the commercialization of advanced reactor technologies. In a future scope, the Team should work to identify key advanced reactor concepts and work with designers of advanced reactors to understand where critical data is being used to support safety and licensing decisions and capture the information in NAED.

2. As previously mentioned, there are several other experiments that are relevant to advanced reactors, specifically those related to overheating of a fast reactor core that is cooled by liquid sodium. These experiments were performed to support the safety evaluations that were being carried out for the (FFTF) and the (CRBR). Of particular interest for the associated behaviors were the superheat needed to initiate boiling of the sodium coolant and the voiding rate that would occur given a specific power level in the core. These may already be in the OSTI archives, but this should be verified, as part of future scope, to assure these experimental studies are not lost.

3. One additional gap identified, which needs to be addressed, is how to include documents or experimental records in long-term archival that have been found by this effort, and the previous work scopes on this topic (Reference 1 and 2), which are not currently included in a long-term storage location. These could be documents in open literature which are not currently captured within OSTI or similar databases but could also include hard-copy records or original experimental media that have been uncovered and not included in any database. The future task would be to generate a framework for organizations and/or individuals who have retained these records and have them submitted to a database to be archived.

4. The final future step would be to perform an in-depth research effort on the programs considered at high risk that do not fall into the previous three future actions. The Team would take the experimental list that is currently considered high risk and prioritize the list based on the significance of the experimental program in supporting the reactor safety basis and the perceived risk of potential data loss. Highest priority would be given to near-term licensing of advanced reactor concepts. The Team would then work from the highest to lowest priority to perform in-depth research on each experiment/program to capture the key references that could be found or determine if data has already been lost.

8.0 Summary

The four tasks stated in the SOW were addressed by:

a. Classification of the experimental programs from Reference 1 according to the coolant type each program represents was completed.

b. A definition of what criteria must be met to consider a program as archived was developed. This definition was then applied to each program from Reference 1 to determine the archival status of each program.

c. An investigation was performed into many programs that were deemed at high risk of being lost. This focused on programs that were performed at U.S. national laboratories, universities, and programs that were conducted internationally.

d. Finally, the Team investigated firsthand accounts of two programs/events, as these references can provide additional insight behind the technical conclusions of an experiment/experience into the social, economic, and political climate during the events.

With the experiences provided by this effort, the great value of having experimental data archived and easily retrievable is clear. The results show that roughly one-third of the programs included in Reference 1 can already be considered sufficiently archived and many of the key references are now captured within a single database. This will allow a future researcher, designer, or licensing professional to quickly focus in on key experiments for specific reactor coolant types. While one-third of the experimental programs can be considered archived, that means two-thirds of the experiments require additional evaluation to track down the key references and ensure they are archived before they are lost.

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