Project Summary / Abstract, DE-FOA-0001817, Advanced Reactor Development Projects: The Autoignition of Nuclear Power Plant Explosions, ARD-20-21608
PROJECT SUMMARY / ABSTRACT: Several files follow this Abstract to complete this proposal.

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ABSTRACT

A fluid transient disaster proceeds unchecked throughout U.S. industries, e.g., hundreds of ongoing small explosions and previous large scale catastrophic explosions caused by fluid transients destroy nuclear reactor piping and buildings, and transients also destroy 13 billion dollars a year in U.S. water mains, and explode gas pipelines to kill or maim people every year. Documented in two parallel theories, fluid transients crack pipes and compress flammable gases to cause explosions. The Leishear Explosion Theory explains pipeline explosions and forges a Potential Inadequacy in the Safety Analyses for the existing U.S. reactor fleet, future nuclear reactor designs, and operating reactors world-wide, where the next major nuclear accident is expected before 2038. The Leishear Stress Theory defines the common cause for oil pipeline and water main breaks, and defines the primary cause for nuclear reactor piping breaks. The Three Mile Island meltdown and explosion, a gas pipeline explosion, water main breaks, and a reactor piping explosion will be researched to understand and avert nuclear power plant catastrophes.

LEISHEAR EXPLOSION THEORY

The validity of this explosive new technology is clearly evident through Dr. Leishear's previous publications, but this additional two year research project will provide much needed corrective actions. Explosions in gas pipelines and nuclear power plant piping systems are similar, except that the flammable gases differ. Hydrogen and oxygen are generated in nuclear reactors, and methane is transported in gas pipelines, where trapped air provides oxygen. Autoignition occurs when a flammable gas is compressed inside a piping system, the gas is then heated to its autoignition temperature, and ignition occurs when the gas mixes with sufficient oxygen to maintain combustion. An explosion then occurs in microseconds. That is, explosions are the actual causes of previous nuclear reactor piping cracks and equipment damages and gas pipeline ruptures, such as the Hamaoka piping explosion that shredded pipe like a paper firecracker. Hundreds, and perhaps thousands, of explosions have been misdiagnosed as water hammers in reactor systems, where reactor piping explosions and damages continue to occur. Additionally, five to ten major gas pipeline explosions occur every year. The reason that pipeline explosions are included in this research is that lives are being lost, and the analyses are nearly interchangeable for reactors or gas pipelines – only the type of gas, the amount of gas, and pipe sizes change.

Explosions occur when pumps, valves, or compressors are operated, where these actions cause fluid transients to compress gases and start the autoignition process. Explosions typically occur inside the piping, but may also initially occur inside the piping to then ignite flammable gases downstream of a safety valve or leak. At Fukushima and Three Mile Island (TMI), hydrogen explosions occurred inside the reactor system and hot combustion gases exhausted to explode in the reactor buildings, where hydrogen had accumulated in the buildings earlier in the accidents. In fact, a TMI hydrogen explosion was considered to be a hydrogen fire prior to this research. Smaller reactor piping explosions occur during pump startups. Similarly, eight people were killed at San Bruno in a gas pipeline explosion, where air accumulated at a system low point. Loss of life and damage can be stopped.

LEISHEAR STRESS THEORY

An ASME text ("Fluid Mechanics, Water Hammer, Dynamic Stresses, and Piping Design", by R. Leishear) and numerous publications document the effects of fluid transients on dynamic stresses and fatigue failures. Some modeling is yet required, which is pertinent to fatigue cracks in nuclear reactor piping, as well as 250,000 water main breaks per year in the U.S. Due to similarities between liquid transients and explosion transients in piping, water main systems will be studied to simplify analysis, where results can then be extrapolated to nuclear reactor piping fatigue failures due to explosions.

BACKGROUND RESEARCH AND CAPABILITIES

To date, thousands of hours and more than $130,000 have been voluntarily invested into this explosions research, where 40+ peer reviewed Conference and Journal publications document the progressive history of this research (R. A. Leishear, 2002 - 2019). To complete these research papers, more than 770 hours of classes were completed around the world in nuclear reactor computer aided design, combustion, fluid flow, piping failures, corrosion, and nuclear reactor law, in addition to all of the University of South Carolina courses required for a PhD in Nuclear Engineering. Also, Dr. Leishear completed a Mechanical Engineering PhD in 2005, along with more than 3700 hours of engineering training at Savannah River Site, where he served as a research engineer at Savannah River National Lab.

PROJECT DESCRIPTION

To perform this research, the processes leading to explosions require computer aided models to fully understand accidents. Accordingly, reactor physics, thermal hydraulics, thermal-fluid transients, and combustion all need to be modeled to understand the TMI explosion. To support this TMI research, experimental modeling of a piping explosion at Hamaoka, Japan, a gas pipeline explosion at San Bruno, and fatigue failures will be investigated, where an understanding of these smaller explosion models will introduce an understanding of the larger TMI explosion.

MAJOR TASKS (PHASES, PLANNED APPROACH, AND METHODS EMPLOYED)

The following models are required, in addition to sub-models to investigate each model topic. *Model 1*: Gas pipeline explosions; *Model 2*: Piping fatigue stresses and ruptures; *Model 3*: Validation of TMI reactor physics and thermal hydraulics; *Model 4*: TMI High temperature thermodynamics subroutine; *Model 5*: TMI Reactor physics high temperature modeling; *Model 6*: TMI Fuel depletion effects; *Model 7*: TMI Loss of coolant and reactivity accidents; *Model 8*: TMI near-meltdown conditions; *Model 9*: Hamaoka and TMI piping explosion modeling. Models will be developed and validated where possible, using NRC (Nuclear Regulatory Commission) and NQA-1 approved computer programs as applicable, i.e., Polaris, Keno, Parcs, Relap5, Frapcon, Fraptran, Origen, AFT Impulse, Fluent, Ansys, and LS Dyna.

MAJOR DELIVERABLES

The deliverables will consist of a series of ASME (American Society of Mechanical Engineers) and Combustion Institute (CI) papers that will describe the results of this research. To be published primarily after research completion, writing of these papers will parallel research progression and will include the following papers, at a minimum. *Paper 1*: “Gas Pipeline Explosions”; *Paper 2*: “Gas Accumulation Events / Fatigue Cracks and Ruptures”; *Paper 3*: “TMI Normal Operations”; Modeling; “Dynamics and Pipe Stresses During Fluid Transients”, “Gas Pipeline Explosions; *Paper 4*: “TMI Steam Line Failure and Reactivity Accident Validations”; *Paper 5*: “Hydrogen Generation During TMI Meltdown Conditions”; *Paper 6*: “Hamaoka Nuclear Reactor, Hydrogen Explosion Modeling"; *Paper 7*: “TMI Nuclear Reactor, Hydrogen Explosion Modeling”.

PROJECT SCOPE AND OBJECTIVES

The primary objective for this research is to investigate the Three Mile Island hydrogen explosion and related piping failures. The goal of this research is to stop explosions in nuclear power plant and gas pipelines, where corrective actions will be considered. The project scope consists of a series of computer models, where comprehensive, NRC approved computer programs are unavailable to fully model reactor accidents that describe the sequence of events from normal operations, through meltdown conditions, and on to explosion conditions. Consequently, this project will investigate normal and near-accident reactor conditions using NRC approved computer codes to construct final combustion and explosion models. To validate nuclear plant explosion models, engineering computer models for gas pipeline explosions, water main breaks, piping rupture, and piping fatigue cracks will be used to create a cohesive explosion theory.

POTENTIAL PROJECT IMPACTS, PROJECT BENEFITS

This work is important to national safety and cost effective operations of pipelines and the U.S. nuclear reactor fleet, as well as future reactor designs. Explosions can be stopped during meltdown accidents, and during routine nuclear reactor operations and gas pipeline operations. Note that completed work for this research statistically proves that the next reactor meltdown is expected between now and 2038 with a one in two probability of a major radioactive release, which can be prevented through the corrective actions investigated during this proposed research. That is, this research will provide corrective actions, and world-wide safety problems can be stopped. By combining these joint research projects to investigate pipeline breaks and explosions, environmental damages can be stopped, property damages can be stopped, and indirect deaths can be stopped for existing and future nuclear power plant designs.

Leishear Engineering LLC

U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

THE AUTOIGNITION OF NUCLEAR POWER PLANT EXPLOSIONS

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There is a reasonable risk of a nuclear power plant explosion like Fukushima, which can be prevented

Ongoing, smaller explosions similar to the Hamaoka nuclear plant explosions, can be prevented

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TECHNICAL NARRATIVE

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EXECUTIVE SUMMARY

The facts are clear – lives are at stake – a nuclear reactor accident can happen at any time, and there is a one in two probability of a Fukushima type radioactive blast into the air and across the globe when this meltdown occurs. At this moment in history Dr. Leishear is the leading researcher to stop this disaster – there will be followers later but not now. Not only can this explosion be prevented, but yearly deaths and multi-billion dollar damages can be stopped as well, where validation investigations of gas pipeline explosions and water hammer induced water main breaks are required as part of this research. Evaluations of gas pipeline explosions and water main breaks are required to validate nuclear accident explosion models due to the limited, available experimental data for nuclear plant systems. This research project is the next step to prevent disaster. These claims may seem bold, but Dr. Leishear voluntarily dedicates his life as proof – he has the training, skills, knowledge, and drive to finish this in-process research, and this research will prevent needless deaths during environmental nightmares. The merit of this work is the question, and the magnitude of my theory answers that question and earns the approval of this grant request. To prove this statement, consider the required research to stop death and destruction.

Figure 1: Nuclear Power Plant Pump Restarts Autoignite Explosions (Fukushima shown)

Objectives

The objective of this research is to quantitatively prove a common cause for nuclear power plant explosions and to investigate preventive actions. This research explains ongoing explosions in US nuclear power plants, Fukushima explosions, a Three Mile Island hydrogen explosion, and other nuclear power plant piping explosions around the world. No fatalities were attributed to the TMI-2 accident, but 141 indirect deaths were attributed to the Fukushima accident, which occurred during relocations following the accident. That is fatalities result from large radioactive releases. These accidents are caused by compressing flammable hydrogen and oxygen to autoignition and explosion, where this common mode dieseling process, called the Leishear Explosion Theory, is primarily initiated by pump and valve operations. That is, explosive new technology for nuclear reactors proves that hundreds of ongoing smaller explosions and previous large scale catastrophic explosions have a common cause. Although conference and journal publications have proven the basic theory, existing publications are inadequate to completely understand the complex combustion processes, and those publications are inadequate to recommend preventive actions[1].

Project Goals

The project goals are to investigate the Three Mile Island (TMI-2) meltdown and explosion, a Hamaoka, Japan piping explosion, and smaller gas explosions in US nuclear reactor systems. This proposed two year project will prevent explosions at existing and future advanced reactor nuclear power plants. To do so, a series of computer simulations will be performed that will investigate interrelated issues that will include reactor physics, reactor chemistry, thermal hydraulics, combustion, and resultant explosions.

The resultant research will include seven, conference ready, publications and animated computer models of reactor processes and explosions. Preventive actions will be recommended during this research, where complex reactor system models will provide new insights into the explosion processes. This research is applicable to the existing U.S. reactor fleet, as well as future nuclear reactor designs, reactors throughout the world, and is incidentally applicable to gas pipeline explosions and water main breaks.

Expected Results

The outcomes of this research will include recommendations to prevent nuclear reactor piping damages due to small-scale explosions, recommendations for regulatory changes to minimize risks for off-normal reactor meltdown accidents, recommendations to prevent large scale radioactive releases during meltdown events, and parallel recommendations to stop gas pipeline explosions that kill people every year. To date, regulatory agencies have failed to recognize these scientific advancements, where explosions inside piping have been misunderstood since the 1950s, and large explosions associated with nuclear reactor meltdowns are misunderstood as well. In fact, present US NRC regulations do not provide adequate safety regulations to evaluate reactor accidents with respect to explosions, and in-process research shows that the next nuclear reactor meltdown can happen any time between now and 2038, with a one in two probability of a large radioactive release like Fukushima, as shown on the cover sheet of this Narrative. Preventing an impending meltdown is beyond the scope of this research, but a major radioactive release can be prevented in the event of a meltdown. In short, the primary, long-term goal of this research is to change existing safety requirements through legislation to regulate nuclear power plant design and operation to ensure safe nuclear reactor operations.

INTRODUCTION AND MERIT REVIEW CRITERIA

In an effort to comply with FOA format requirements, the directions were followed as well as possible. This Narrative begins with a description of the FOA Objectives, where specific criteria are addressed. However, the Scope has been placed out of the specified order, where the Scope is placed after the Technical Description. That is, the Scope is very detailed, and a technical presentation of this project should lead into a better understanding of the Scope. The Scope and the Technical description have been included within the requirements of Criterion 1 – these topics are applicable to support the Criterion evaluation. Also of note, extensive voluntary research has been completed in preparation for this project, and some of that research is very briefly presented in this Narrative. Since this volunteer research is integral to this proposal, some of that work is presented in the Past Performance file – previous research dedicated to this project constitutes Past Performance.

The FOA further requires that each Merit Review Criteria be separately identified, and accordingly each criterion (Criterion 1 and Criterion 2) from Section V of the FOA is identified and defended after the Scope is presented. That is, the Scope and Technical Background provide a path of understanding to the evaluation criteria.

Additionally, a "Sample and Evaluation Criteria and Rating Scale" is available for use on proposals

[1] This explosion cause also explains off-shore oil rig explosions, oil pipeline explosions, and gas pipeline explosions, where most petroleum industry explosions, except gas pipeline explosions, are outside the scope of this research. Gas pipeline explosions are only considered here to validate explosions models that do not otherwise have validations available.

from the DOE "Merit Review Guide for Financial Assistance and Unsolicited Proposals." This document provides a list to represent the minimum required information, but provides clear rating criteria for the contractor. Each of these criteria has been considered during this proposal, and concise responses to each criterion are listed in the footnotes to this Narrative to serve as an aid to clarify contractor efforts to meet FOA objectives.

PROJECT OBJECTIVES

Fluid transients autoignited explosions at Three Mile Island, Fukushima, Hamaoka, and at numerous other commercial nuclear reactor plants in the U.S. and abroad, and this research can stop future explosions by investigating the TMI and Hamaoka accidents to determine effective means of explosion prevention. This fluid transient disaster proceeds unchecked throughout U.S. industries, i.e., not only do transients cause ongoing small explosions and previous large scale catastrophic explosions to destroy nuclear reactor piping and buildings, but transients also destroy 13 billion dollars a year in U.S. water mains, and explode gas pipelines to kill or maim five to ten people every year. Even so, the objectives for this research are to investigate nuclear power plant explosions and preventive actions.

There are two parallel objectives to pursue this research: 1) Investigate the common cause of fluid transient explosions; 2) Determine preventive actions to stop nuclear power plant explosions. The primary objective of preventive actions is to save lives, property, and the environment. This objective cannot be performed without first investigating explosion cause and effects, and computer models will be used for this purpose[2]. Footnotes are used throughout this discussion to cross-reference Merit Review Criteria to text entries, which enables specific identifications and concise explanations of FOA compliance, and supporting text addresses and addresses Merit Review Criteria as well – more than one footnote may be used for a single criterion.

Reactor Model Selection

To be used as explosion model examples for the rest of the nuclear reactor industry, the TMI-2 and Hamaoka hydrogen explosions are the primary explosions to be modeled, and supporting models will be performed as required. Since this research is first-of-a-kind, there are no available experimental explosion results to validate computer models. However, there are definitive similarities between this research and other industries, and model performance is essentially the same – only the subtleties of fluid dynamics differ. That is, experimental data from other industries can be used to validate nuclear system computer model results for this research. This validation step is crucial for quality control and proof of principal for the computer model results.

Model Investigations

The common thread for this research is the fact that the explosion cause is the same – only the magnitude of the explosion and the extent and type of damage changes. Accordingly, explosions of varying magnitudes can be investigated to discern the complex relationships between fatigue cracks, piping ruptures, and explosions in reactor buildings. Numerous models will be evaluated as model complexity increases from simple pipe failures to entire nuclear reactor systems. All of the selected models carefully build engineering principles to explain and prevent nuclear power plant explosions. Many more models could be performed, but this research is intended to provide a technical foundation for other engineers, perhaps hundreds of engineers, who can build on this work to make reactors safer to operate.

Preventive Actions

As the TMI-2 reactor system is progressively investigated, variables can be modified to determine the effects of venting flammable gases from the RCW system, and to determine appropriate controls for venting. At present, venting effects on explosion prevention are not understood.

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[2] *FOA requirement:* Since this research extends the invention of a new theory (The Leishear Explosion Theory) where knowledge did not previously exist, this research has an extremely high and outstanding *degree to which the proposed work identifies and/or makes progress on new/existing concepts.* Specifically, Dr. Leishear invented a theory and this research further proves his theory to implement methods to prevent large radioactive releases and prevent deaths.

Compliance with FOA Objectives

This research "supports innovation and competitiveness of the U.S. nuclear industry" and "includes the development of technologies that improve the capability of the existing fleet, and design and engineering processes." Specifically this research is based on theory that that Dr. Leishear invented and published through ASME to describe the complex interrelationships between explosions and nuclear reactor operations. This breakthrough research is the basis for this grant request, which will provide computer modeling of explosions in reactors and then use those models to provide corrective actions to stop those explosions. As a general rule for engineering, if one can understand the problem, a solution is easier to find. As second rule of engineering – success is better than failure. Success for this research is built on years of dedicated, unparalleled studies and research to understand all aspects of nuclear power plant explosions.

This research also meets the following FOA objectives[3].

- "Broad applicability to multiple reactor technologies and type" – This explosions research is applicable to PWRs and BWRS, and may be applicable to new reactor designs as well, in case where hydrogen can be compressed by fluid transients to cause ignition.
- "Provides unique/new ideas that will improve the existing fleet" – Some of the ideas presented here have been published, but all in all this research yields step change to the understanding and prevention of nuclear accident explosions and explosions during routine operations.
- "Potential for future U.S. nuclear power deployment, and U.S. nuclear technology leadership" – Implementation of prevented actions proven by this proposed research is essential to nuclear reactor safety.

This research is applicable to:

- "Plant auxiliary and support systems – This research is applicable to the RCW system.
- Modeling and simulation of various elements of plant life cycle" – Models will be performed for the RCW system explosions for accident conditions and normal operations.
- "Procedures, processes, and methodologies that can impact operational efficiencies" – Prevention of meltdowns and RCW piping cracks increases operational efficiency.
- "Efforts to address regulatory and licensing issues with the NRC" – Explosions have been misunderstood for decades, which affects NRC regulations [17 and 18], i.e., regulations cannot be correct if the technology that supports them is not understood.

This "project has manageable and achievable project plans." Specifically, a select group of models were chosen to fit within a two year schedule, and provide results that can change reactor operations world-wide. Many hours of careful study have been dedicated to study the project schedule to ensure success, and many years of successfully managing DOE projects at Savannah River Site as a project engineer and Principal Investigator ensures success.

CRITERION 1- FEASIBILITY, COMMERCIALIZATION, AND UTILIZATION OF THE TECHNOLOGY

Criterion 1- Feasibility, Commercialization, and Utilization of the Technology • Feasibility of the plan to develop the proposed technology, including adequacy of cost and schedule justifications and the identification of high-risk challenges and mitigation strategies, to meet the goals and objectives of the proposal. • The degree to which proposed technologies, methodologies or capabilities fill a known, existing gap in domestic nuclear technology capability and/or provide for improved deployment potential of advanced reactor designs. • The degree to which the proposed technologies, methodologies or

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[3] *FOA requirement:* To ensure FOA compliance, objectives were reviewed item by item, and this resultant list thoroughly explains the *degree to which proposed technology or methodology meets the stated objectives of the funding opportunity announcement* and the *appropriateness, rationale, and completeness of the proposed Statement of Project Objectives.*

capabilities can be commercialized and applied by industry to improve construction, commissioning, and/or operations of advanced reactor designs.

The Urgency of This Research

Using probability and statistics theories that are identical to those used for probabilistic risk assessment (PRA) to ensure reactor safety, the next nuclear accident can be predicted (Leishear [15]). If PRA is acceptable to predict reactor safety, then PRA is acceptable to predict accidents. The calculation results predict an accident with 95% confidence, and the next nuclear reactor meltdown is predicted to occur between now and 2038 with a one in two probability of a large radioactive release at the same time. Lives have been lost in previous accidents, and lives are expected to be lost in future accidents[4]. Nuclear reactor designs are presently unsafe. This conclusion is discussed further in the Past Performance / Research to Date file of this FOA, where the magnitude of this claim merits additional discussion.

Preparation for Explosion Research

Extensive research was performed in preparation for computer modeling. More than 20,000 hours of volunteer research have been performed over the past 25 years to support fluid transient and explosions research, and the past 3-1/2 years have been dedicated full-time, 40 to 60 hours a week, to this research. The technical background for this explosion research is provided in the Past Performance / Research to Date file of this FOA. Numerous papers summarize this background research as part of this ongoing project (References 1-23). This initial research clearly demonstrates Dr. Leishear's ability to manage the remainder of this project, which will provide the required models to better understand and stop nuclear power plant explosions.

TECHNICAL DESCRIPTION

The crux of this research is that hydrogen autoignites for specific temperature and pressure combinations, as summarized in Fig. 2 (Leishear [9]). Multiple explosion and autoignition scenarios have been proven to occur inside reactor cooling water systems. Note that there is a curve in Fig. 2 that defines hydrogen and oxygen explosion to the right of the curve and no ignition to the left of the curve. The curve has three well defined slopes, where each slope results from a specific chemical reaction in the multiple reactions that occur during hydrogen combustion. When combined temperature and pressure combinations exist to the left of this curve, autognition results in a flame (deflagration) or explosion, which is a sudden release of energy. Explosions can further result in flames or detonations, which are high pressure explosions with associated shock waves. For adiabatic hydrogen-oxygen combustion, flames travel at subsonic velocities and detonation waves travel at supersonic velocities, where hydrogen pressures in the reactor system are multiplied by a factor of 55 during detonations[5]. To obtain this point on the curve, an adiabatic compression due to a fluid transient, or water hammer, was assumed and calculations were performed accordingly.

Since this research is primarily a TMI explosion investigation, one point on this curve is of particular interest. That point is annotated as "TMI Piping Explosion Downstream of PRV," and heated hydrogen is exhausted to an oxygen rich air environment - this explosion describes two separate fluid transient explosions that occurred during the TMI-2 accident. Note that the temperature and pressure both increase by more than a factor of ten due to the explosion. These conditions occur at the point of detonation, and

[4] *FOA requirement:* This research project represents the only emerging technology to date that is working toward the prevention of fatalities during nuclear accidents, and this research is therefore an immense and outstanding *anticipated benefit of the proposed work in comparison to current commercial and emerging technologies.*

[5] *FOA requirement:* Since this research is founded in the fundamental principles of combustion and fluid dynamics, or water hammer, that are in turn based on the fundamental principles of physics, this research exhibits an outstanding *degree to which the proposed work is based on sound scientific and engineering principles*. Detailed calculations are provided in the Past Performance / TMI Hydrogen Explosion Calculations file, and many peer reviewed conference and journal publications document this research.

the more gas that is present, the larger the zone of high pressure. For example a firecracker would nearly be a point source that spherically expands outward, and a pipe completely filled with hydrogen would be a bomb. As discussed, the cause of the TMI hydrogen explosion was autoignition (or self ignition).

A second explosion accident is also evaluated in this research, and this Hamaoka piping explosion is recorded in Fig. 2 and shown on the cover sheet of this Narrative. In this accident, the explosion pressures are affected by the fact that the piping explodes. Models will provide insights into this complex process.

TheTMI-2 and Hamaoka explosion models will be coupled to other model results to investigate explosions and actions to prevent those explosions. The goal of this research is to model explosion processes and investigate operational methods to stop explosions before they happen, i.e., the sole purpose of this research is to improve reactor safety.

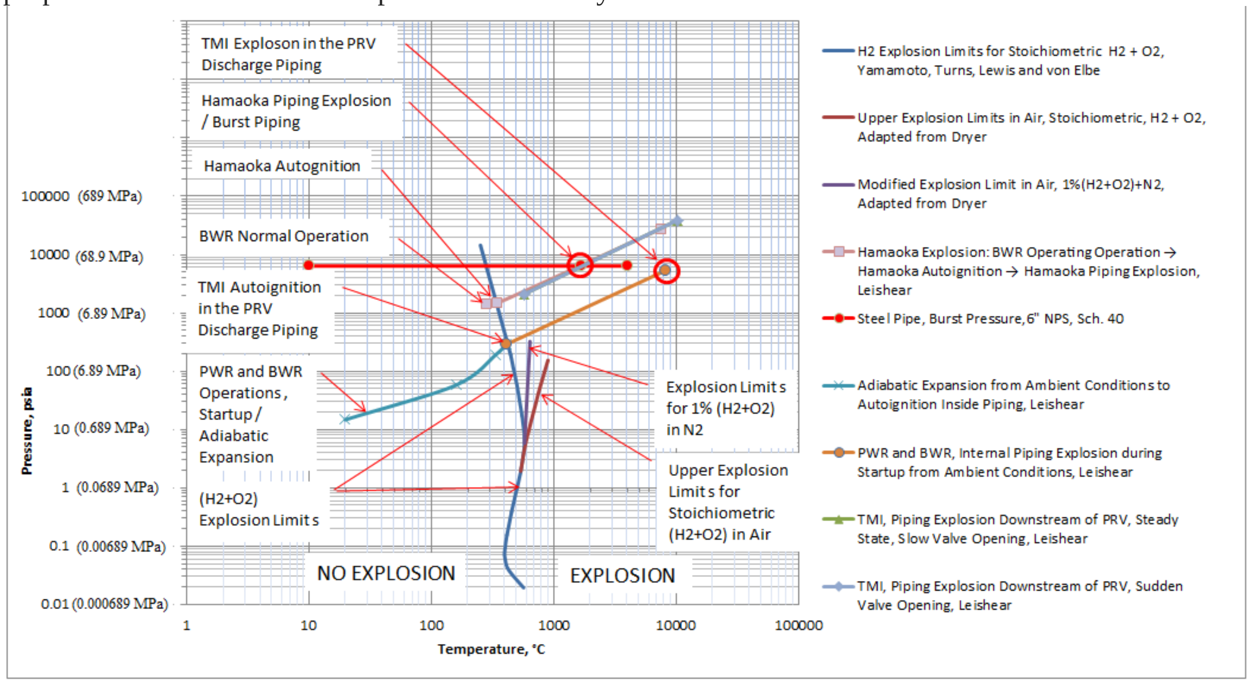

Figure 2: Autoignition Temperatures for Normal Reactor Operations and Accident Conditions. Calculations prove that adiabatic compression explodes hydrogen and oxygen[5] (Leishear [12]).

Technology Implementation[8]

To implement this research into existing reactors, current high point vents and equipment may be utilized, but additional equipment may be required. Also, advanced reactor designs may be affected by this research, and this research should be considered by designers for reactor designs to ensure safety. A comprehensive review of all reactor designs is outside the scope of this research.

Even so, anticipated preventive actions can be considered. In the event of a reactor meltdown, hydrogen needs to be vented while the RCW system is being filled. This scenario will be investigated as part of this research to ensure that back pressure from relief valves does not cause autoignition. To also be investigated, Relap5 should be able to model the use of continuous RCW recirculation to move hydrogen to the high point vent where it can be removed during normal operations. However, this Relap5 capability has not yet been validated, and calculations outside the scope of Relap5 capabilities may be required, and this research will likely cause nuclear reactor operators to further evaluate their reactor system designs.

Research focuses on solving an extremely complex problem to save lives and stop damages, and effort is devoted to the problem solution for one reactor to serve as a model for many different reactor deigns, which are outside the scope of this research. This research serves as proof of principle for explosion causes and preventive actions.

Required Tasks

In short, I have worked part time on this research for many years, and have dedicated most of the past three and a half years toward the pursuit of this research to ensure reactor safety. To prepare for this research and complete the required tasks, I have completed extensive, full time education, where I already have a Ph.D. in Mechanical Engineering and I am currently working on a Ph.D. in Nuclear Engineering. I have completed more classes than required for this Nuclear Engineering degree to ensure that I am adequately prepared for this research. In fact, this research will serve as the Dissertation capstone for this in-process Ph.D. An extensive list of courses to support this research is provided in the FOA, Past Performance file of this FOA to describe completed university classes, and classes completed throughout the U.S. and other countries to learn all of the requisite computer codes and technologies required for this research.

Required tasks are grounded in this extraordinary education and published research[6], and the specifics of these tasks are described above in the Project Scope. An overview of pertinent computer codes follows to provide some additional understanding of the modeling processes.

1. Modeling of gas accumulation events (thermal fluid transients) will be performed using AFT Impulse. This phase of research will further demonstrate that gas accumulation actually decreases the pressures that occur during fluid transients.
2. Hamaoka piping explosion will be performed modeling using Fluent and LS Dyna. Fluent has the capability to model combustion and explosion events. To validate this capability, gas pipeline explosions and the Hamaoka piping explosion will be modeled, where combustion, explosion and structural failures will be considered, using Fluid Structure Interactions with Fluent and Ansys. The complex structural dynamics of the pipe explosion will also be investigated using LS Dyna, where LS Dyna input will be obtained from Fluent output. This LS Dyna model can then be compared to the explosion photos in the literature (Leishear [12]) for comparisons between CFD damage predictions to the actual explosion damages.
3. TMI reactor physics will be performed modeling using Polaris. Although some reactor code data is available to obtain reactor lattice physics properties, the research completed here will consider a wide range of temperatures that occur during a meltdown, where TMI core temperatures have been estimated near 2300°C.
4. Validation of Polaris TMI reactor physics models will be performed using Keno, as schedule permits. The only certain method to validate Polaris lattice calculations is to spot check calculations using Keno, where Keno calculations for all lattice calculations would be prohibitively expensive and time consuming.
5. A thermodynamics subroutine will be performed for Parcs and Relap5. The U.S. NRC has provided a Relap5 computer code for the TMI, Unit 1, which is similar to the TMI, Unit 2 that melted down. Code modifications for my Unit-2 models may be approximated from data in the literature.
6. Fuel depletion effects will be evaluated using Origen. Although, the TMI meltdown occurred soon after initial startup, fuel depletion needs consideration to ensure Parcs modeling accuracy, but Parcs input requires a single fuel description with respect to nuclide concentrations in the fuel rods.
7. Normal operations and steam line failure will be modeled: Coupled, TMI reactor physics and thermal hydraulics will be modeling using Relap5 and Parcs. Thermodynamics data and Polaris data will be used as inputs for Parcs to perform coupled calculations with Relap5, where coupled calculations compare the results from each computer code while data processing occurs. Once the codes are coupled to evaluate normal operations, off-normal operations can be evaluated. Specifically, a loss of steam line accident and a reactivity accident can be evaluated. In a series of publications, several independent researchers investigated and modeled a steam line failure due to reactor core damage at TMI, Unit 1. By using new code results for comparison to the published results of others, Parcs and Relap5 codes can be validated.

[6] *FOA requirement:* Extensive study, research, and publications background this research to demonstrate an outstanding *extent of prior use, research, development or Application of the proposed technology and appropriateness of how the prior work relates to the proposed Application of the technology.* In other words, years have been dedicated to background this proposed research.

8. Meltdown: TMI reactor physics and thermal hydraulics modeling using Relap5 and Parcs. Parcs has the ability to model up to the time of the reactor meltdown and model partial coolant blockage of the reactor core, where the blockage is established by previous NRC reports. Consequently, a reactor restart can be mimicked using a partial blockage condition to determine the flow rates in the safety valve piping, where this flow rate will be used as input to the Fluent combustion model.
9. Meltdown: TMI reactor physics and thermal hydraulics modeling will not be performed using Melcor. Melcor was developed to better analyze reactor meltdown accidents, where a Melcor model could have provided partial validation of a meltdown model.
10. Steady state hydrogen generation in reactors is planned for modeling using Frapcon. Frapcon has the ability to model hydrogen generation during normal operations, and Parcs has the ability to use Frapcon input for its calculations. These models are optional, but provide better insights into TMI operations.
11. Transient hydrogen generation in reactors (accident conditions) will be modeled using Fraptran. Fraptran has the ability to model hydrogen generation during accident conditions, near meltdown, and Parcs has the ability to use Frapcon input for its calculations. This Fratran feature will determine the flow of hydrogen into the RCW system due to Zircalloy fuel rod decomposition. However, calculations for radiolytically and thermolytically generated hydrogen will need to be performed using spread sheets. Parcs and Fraptran are not coupled, but the manual entry of the data into Parcs will have the same effect as a coupled model. Trace is the most recent thermal hydraulics code endorsed by the NRC, but the Relap5 capabilities are required for this research.Relap5 effectively models sonic flow through valves while Trace does not. The output of Relap5 using Fraptran can then be used as partial input to Fluent for an uncoupled model of the reactor explosion, which is a reasonable engineering decision based on PI experience in gas dynamics. Hydrogen generation will be set to the 703 pound estimate of Henrie and Postma [14]. The release of hydrogen while filling this reactor will also be investigated as an explosion prevention measure.
12. Explosion modeling of the TMI combustion process will be performed using Fluent and Ansys. Adiabatic heating of the calculated hydrogen content in the piping will be modeled, and the hydrogen release through a safety valve can then be modeled. The piping to the reactor containment building will be modeled as a simple structure.

PROJECT SCOPE[7]

The scope of this project will carefully evaluate the TMI meltdown and the resultant hydrogen explosion, and to investigate the general methods that will prevent hydrogen explosions following meltdowns and that will prevent hydrogen explosions during reactor restarts and reactor system flow rate changes. The myriad different reactor designs preclude an investigation of all reactors, but this TMI investigation will conclusively define the explosion issues. Of the explosion problems identified above in Section 1.0, Project Objectives, the Three Mile Island accident and explosion presents a clearly defined opportunity to investigate the many aspects of hydrogen ignition. Computer modeling will be performed in the order specified to reduce project risks and build a comprehensive model step by step as knowledge is gained through modeling.

The following models will be executed. There are more than one sub-model for each model, where most of the allotted schedule time will be required to develop a model template. Once a template is developed for each model, most other models are expected to follow in a day or two for each model, where only dimensions, fluids, temperatures, or pressures need to be changed in the computer program. Additional technical modeling issues will be discussed in more detail below (Technical Description).

Piping Rupture Explosions, Model 1 (4 models)

[7] *FOA requirement:* This scope has been very carefully developed, through long hours of study, to ensure that this project can be completed on time and within budget to ensure the *adequacy and feasibility of the Applicant's approach to achieving the funding opportunity announcement's stated objectives,* where the funding objectives are detailed above in the Project Objectives section of this Narrative.

The objective of this model is to validate explosion models, but saving lives is an added benefit. The difference between gas pipeline explosions and nuclear plant explosions is related solely to pipe diameter and the gas – hydrogen in RCW systems, and methane in gas pipelines. Consequently, either hydrogen or methane, natural gas systems can be modeled to understand explosions and flammable gas release.

Sub-models will include 1) Methane- air explosions inside a pipe due to fluid transients, 2) Explosions external to pipes that contain only methane, which is exhausted through the openings to the air, and two different openings will be evaluated, i.e, 2) a rupture due to a sudden longitudinal crack and 3) a rupture due to a sudden circular hole. A fourth model, 5) will evaluate pressure transient during inadvertent, sudden valve closures in a gas pipeline, which caused the San Bruno explosion (See the Past Performance file for further details). Together, these four models will provide an understanding of both fluid transient explosions and autoignition due to supersonic discharge velocities outside of the pipe. This latter explosion mechanism is similar to what happens when hot hydrogen gases are exhausted trough a safety valve in a nuclear reactor. Models will consist of horizontal, flammable gas filled pipes.

Fatigue Cracks and Rupture, Model 2 (6 models)

A 3 inch diameter pipe can be modeled with Fluent, and the model results can be directly compared to published SRS test results (Leishear [19]). This comparison constitutes fatigue stress model validation, and models of 12, 24, and 36 inch dimeter pipes can then be executed to determine and explain wave speed and damping effects. One of these models will be selected to model plastic deformation and rupture, using water hammer waves to simplify the understanding of the underlying physics. Together these 6 models provide an understanding of explosions and fatigue. Models will consist of horizontal, water filled pipes.

Explosions in Reactor Buildings, the TMI-2 Explosion Models

The proposed TMI-2 explosion research will require a detailed study of the reactor physics, reactor chemistry, thermal hydraulics, fluid transients, structural dynamics, and combustion processes. To date, there has been no other study to research this extremely complex process.

The next essential step in this research will be the modeling of the Three Mile Island accidental core meltdown and hydrogen combustion, where this research will bring about an overall understanding of the events that created the hydrogen explosion at TMI. As noted, the basic hydrogen ignition mechanism is nearly identical for the Fukushima explosions in 2011 and is similar for hundreds of smaller explosions in nuclear power plants throughout the world. This hydrogen ignition mechanism causes explosions, where pump and valve operations compress flammable hydrogen to its autoignition temperature to ignite the hydrogen when it contacts oxygen.

The TMI-2 Normal Operations, Validation, Model 3 (4 models)

Confirmation of the TMI-2 reactor operations model is required, where TMI-1 models are available, and a TMI-2 model is recommended. To sequentially verify performance of the models, models will include a steady state TMI-1 reactor model that does not include the RCW system (from U. of Ill.), a TMI-1 model that includes the RCW system (from U. of N.C.), and a TMI-2 model that includes the RCW system, where a TMI-1 code needs to be revised to reflect the TMI-2 piping configuration. Frapcon is an optional model to evaluate hydrogen distribution during normal operations. These four models will ensure that models operate correctly for known conditions.

The TMI-2 High Temperature Thermodynamics, Model 4 (2 models)

The models that are available from the U. of Ill. and the U. of N.C. do not have thermodynamic data for temperatures near the melting point of the uranium oxide fuel. A Matlab subroutine/model is required to run the Parcs/Relap5 program near the fuel melting temperature. These two models will verify that the reactor programs operate at high temperatures.

The TMI-2 High Temperature Reactor Physics, Model 5 (3 models)

The models that are available from the U. of Ill. and the U. of N.C. do not have nuclear cross-section data for temperatures near the melting point of the uranium oxide fuel. Polaris will be used to generate cross-section data, and if time permits a few cross-sections will be validated with Keno. If schedule becomes a problem, an alternative may be to perform the models at slightly lower operating temperatures.

A Matlab subroutine/model is required to run the Parcs/Relap5 program near the fuel melting temperature. These two models will verify that the reactor programs operate at high temperatures.

The TMI-2 Fuel Depletion, Model 6 (2 models)

Origen may be used to investigate fuel depletion effects on model performance, since the TMI-2 meltdown occurred soon after reactor startup. An Origen and a Parcs/Relap5 model would be required for normal operations.

The TMI-2, Accidents, Model 7 (2 models)

Using the comprehensive model developed from Models 3 -6, a steam line failure and a reactivity accident can be modeled. These 2 models can be executed, and compared to published NRC papers for code validation.

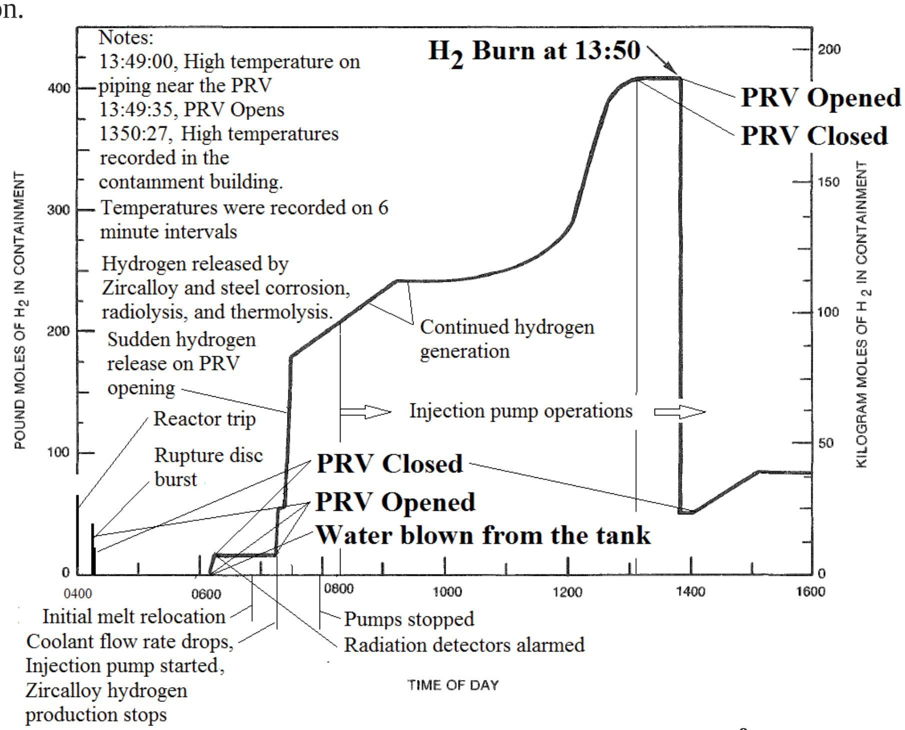

Figure 3: Hydrogen Generation During the TMI-2 Meltdown Accident[8] (Adapted by Leishear [12] from Henrie and Postma [14] and NRC reports)

The TMI-2 Near-Meltdown Conditions, Model 8 (2 models)

Using the comprehensive model from Model 8, the effects of hydrogen generation can be visualized using Fraptran and Relap5, even though much of the hydrogen generation shown in Fig. 3 will not be calculated. Fraptran determines hydrogen quantities for given conditions of the Ralap5 program. Fraptran then interfaces with Relap5 to input the hydrogen volume so that Relap5 can continue calculations to portray the hydrogen distribution throughout the RCW system. This hydrogen distribution is the requirement needed to model hydrogen heating due to fluid transients. The exact hydrogen volume cannot be determined since Relap5 does not have accident modeling capabilities. Knowing the hydrogen distribution from this model and the system flow rates in the pressurizer piping, the hydrogen volume can be approximated from closed form equations. Then the inputs to Fluent are established. Two models are required for this step of research.

The TMI-2 and Hamaoka Explosions, Model 9 (6 models)

[8] From the FOA Q&A, The applicant may use the font and font size of their choosing for exhibits, graphics, and tables, as long as these items are adequately legible to the reviewers (i.e., will not require the use of magnification to read).

With comprehensive models of reactor operations and explosion characteristics completed, the final models of the TMI-1 and Hamaoka explosions can be modeled. Limited model verification will be performed by modeling a Hamaoka model using both a coupled Ansys/Fluent model and an AFT Impulse model, where these two models will be performed for a vertical pipe containing hydrogen. Then, models can be executed for the TMI-1 RCW system for the conditions of safety valve opening and no valve opening. Hamaoka models will be performed for coupled Ansys/Fluent models and non-coupled LS Dyna models. This set of models will be the most complex set of models performed to date, but earlier models will provide a comprehensive modeling foundation. Models will consist of vertical pipes with flammable gases at the top of the piping.

Summary of Selected Models

Complete models of meltdowns and explosions cannot be performed with available technology, since current models cannot restart from a meltdown condition. Melcor could provide additional model insights, but Melcor must be tuned to a specific accident. Melcor was developed for TMI-2, but Sandia possesses the modeling tuning parameters to make the program work properly, and these parameters are unavailable. If DOE chooses to obtain that modeling data, a Melcor model could be performed, but a Melcor model does not fit into the existing two year schedule. In other words, a Melcor model is outside of the project scope. Even so, this judicious set of models will provide reasonable models to understand nuclear reactor explosions and methods to stop them, where preventive actions will be investigated during the execution of applicable models.Relap5/Snap, Fluent, Ansys, and LS Dyna all have graphic video capabilities for animated video displays to understand various processes.

Commitment to Meeting the Statement of Objectives

The selection of the TMI explosion investigation serves as a pilot to understanding in-service reactor designs as well as future reactor designs with respect to explosions. Dr. Leishear has dedicated much of his life to this research, and dedication to the project objectives is ingrained by his past behavior and will carry forward into this project. His experience ensures project success, where he served as a Research Engineer at Savanah River National Laboratory, a quality Assurance Engineer, a Shift Technical Engineer, a Project Engineer, and a Design Engineer. Details of these positions and other pertinent job assignments are discussed in the Past Performance file of this FOA.

CRITERION 1 – MERIT REVIEW CRITERIA

Technical Feasibility

Discuss the feasibility of the plan to develop the proposed technology, including adequacy of cost and schedule justifications and the identification of high-risk challenges and mitigation strategies, to meet the goals and objectives of the proposal.

The comprehensive research effort and resultant technical results to date ensure the feasibility of this research. Dr. Leishear will perform most of the research with technical training from the SimuTech Group to expedite schedule. Dr. Leishear‘s $130,000 personal investment into research, publishing papers, and additional education laid a rock solid foundation to start this modeling phase of the research. That foundation is available to describe the scope of research to date, and the remaining work to be done. Research completed in preparation for computer models is discussed in detail in the Past History / Research to Date file of this FOA.

To document nuclear power plant explosions research to date, twenty of Dr. Leishear's publications are referenced in Appendix A, and those references are based on hundreds of references by others. Together, this documentation forges a proven theory to explain explosions at Three Mile Island, Fukushima, Hamaoka, Brunsbuttel, and in U.S. nuclear reactor systems[9].

[9] *FOA requirement:* Published in a series of ASME peer reviewed papers, combustion and fluids theory were combined with reactor design principles to document and prove that fluid transient explosions are the common cause of most nuclear power plant explosions, where this conclusion exhibits an outstanding and extremely high *degree to which the proposed work is based on sound scientific and engineering principles*.

The success, or feasibility, of this project rests on Dr. Leishear's character and work ethic. At the risk of not sounding very humble, every engineering and scientific team project that he ever led over the past thirty years was a success, regardless of complexity. In fact, he solved many industrial problems that were unsolved for decades. Success does not occur by accident, success is the natural outcome of hard work, tenacity, diligence, and doing what one believes to be right.

What Dr. Leishear believes to be right is that the completion of this research to stop explosions in nuclear power plants must be finished. Dr. Leishear's research proves that explosions are caused by pump and valve operations. This process may be referred to as a fluid transient explosion or the Leishear Explosion Theory. As discussed, several sources form hydrogen in nuclear reactors, sudden increases in flow compress hydrogen, the hydrogen temperature increases, and an explosion occurs when the heated hydrogen contacts oxygen. This process becomes extremely complicated in nuclear reactors, which explains why this discovery has taken more than 60 years to surface in the nuclear power plant industry. Dr, Leishear's discoveries represent a giant step change to nuclear safety. Nuclear power plant explosions can be stopped[10].

Costs

The total cost estimate is .... Costs are detailed in the Budget Justification file of this FOA, which is not supplied in this document.

A major portion of the costs support explosions modeling and research documentation, where 96, fifty hour weeks are planned during a two year period (104 weeks) for the Principal Investigator, Dr. Leishear. This schedule will be hard but workable. That is, this work schedule is reasonable given the fact that Dr. Leishear has worked an average 50 hour week throughout most of his previous 24 year career at Savannah River Site. If he is going to work those hours, he should be paid for those hours - this could be a first. Travel expenses for Quick Books training and travel for conference publications and ASME piping committee conferences and society memberships are included in cost estimates. These conferences and memberships are related to ongoing research. The scope and importance of this research warrants 50 hour work weeks to expedite the results to stop explosions as soon as possible.

Technological Readiness Level

This technology fits into "Basic Technology Research, Technology concept and/or application formulated, or TRL 2. The basic principles have been observed" - explosions in nuclear power plants have been proven to be caused by fluid transient explosions, as described in multiple peer reviewed publications. Explosion "applications are speculative", with some "detailed analysis to support the assumptions - the recommended preventive actions for venting hydrogen to stop explosions has been published, but reactor modeling to prove this part of the theory has not been completed. Examples are still limited to analytic studies" - this research will provide extensive analytical proof of principle for both the occurrence of explosions and the methods to stop future explosions. "Supporting information includes" years of research, which resulted in more than twenty published "references that outline the" explosion "application being considered" - these publications provide simplified mathematical analysis based on physics principles to explain required concepts to continue research. This proposed work will consist of "analytical computer studies" using NRC approved nuclear reactor design codes "with the emphasis on understanding the science" and understanding preventive actions better - experimental work is outside the scope of this proposal, but may be considered at a later date.

Cost Sharing

Cost sharing will be paid from the wages of J. Leishear, and R. Leishear as work proceeds. Cost sharing to perform this work will constitute a 20% fee, and future contracts for LELLC are not expected unless future DOE research is funded after this contract. A 20% cost share was selected since "The

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[10] FOA requirement: Since new technology (the Leishear Explosion Theory) has already been invented as part of this ongoing research, this research will further prove that technology and demonstrate preventive actions, there is an outstanding and exceptional *likelihood of developing a new successful technology*.

recipient's cost share must be a minimum of 20 percent of the total allowable costs for applied research projects or other efforts that are lower on the technology readiness level (TRL) spectrum," and this technology is rated as TRL 2.

Schedule

Schedule justifications are based on decades of Dr. Leishear's project scheduling for many projects at Savannah River Site for Savannah River Nuclear Solutions and Savannah River National Laboratory. Basically, the schedule consists of a series of computer models and a series of publishable draft papers to document that modeling. The computer model sequence was judiciously selected to reduce project risks, and build a comprehensive model step by step as knowledge is gained through modeling. The milestones for this project are the publishable papers that will be formatted for ASME and Combustion Institute Conference presentations – some publications will be published during the project and some will occur later. Many hours have been spent carefully reviewing this schedule to ensure that it can be executed in a timely manner, where decades of engineering leadership, years of project management experience, and computer modeling experience were focused to establish this schedule. Milestones (publications) are shown in Fig. 4 and Table 1, computer modeling tasks are shown in Fig. 4, and decision points along with success criteria are shown in Fig. 2 – this data was copied from the Project Management file for this FOA.

Risks[11]

Perhaps the most extraordinary risk to this research is the scope of skills required to complete this study. To overcome this extremely high hurdle, Dr. Leishear performed extensive study, associated literature reviews, and pertinent calculations in preparation for this explosion modeling. Not only were extensive theories from multiple fields of study required, but new theory was invented on-demand to explain nuclear plant explosions. Of paramount importance to this project, the risk of not performing this research dwarfs the risks due to other risks. Lives are at stake.

The Project Management File identifies 53 risks, and provides a detailed list of those risks and appropriate risk responses. Table 3 provides the metrics that were used to perform a qualitative risk assessment for this project, and Table 4[8] provides risk assessment impacts for the higher risks that were considered. Figure 5 visually compares all 53 mitigated risks to the unmitigated risks, where the risk responses reduced the sum of the risk factors by 69%.

Numerous risks were mitigates as listed, but two mitigations merit additional attention. First, a careful study of the technical risks concluded that additional expertise is warranted for successful research. Dr. Leishear will perform all modeling, but SimuTech, a contractor for Fluent services, will provide a specialized tutorial to expedite this research, and ensure that computer programs are efficiently executed. Second, Dr. Leishear is the sole researcher for this work – if he dies or becomes incapacitated, research stops. This risk is mitigated by periodic research publications, and the risk of his death (Risk factor = 5) is far less than the risk of not stopping large radioactive releases (Risk factor = 25). In other words, the fatalities of many are of greatest importance than the loss of one person[12].

Risk Summary

In short, this research is imperative to stop death and destruction, which represent the highest risks with respect to this research, and this research will provide the mitigations to those risks. That is, the highest external risks are associated with accidents that kill people, i.e., nuclear power plant and gas

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[11] *FOA requirement:* Based on project management experience and education, a detailed risk assessment for risks and mitigations was performed and documented in the Project Management file. Part of that file is reproduced in this Narrative to demonstrate an outstanding *degree to which the Applicant has identified high-risk challenges and presented reasonable mitigation strategies.*

[12] FOA requirement: Risk analysis shows that there is *adequacy and availability of proposed personnel, facilities and equipment to perform project tasks*, where the risk of not performing this research far surpasses the risk of personnel loss.

pipeline explosions.[13] Most internal project risks are mitigated by reducing risk responses to low or very low values, but a few risks are not, and the more significant residual risks are summarized as follows.

Extreme risks

1) The prevention of a nuclear reactor meltdown that is predicted before 2038 is outside the scope of this research, but death and significant damages may be averted, or mitigated, by prevention of large radioactive releases.

Very high risks

2) Fluent modeling software procurement represents a very high schedule risk that requires advance payments by DOE. DOE payment in advance seems appropriate, given the investment of time and money by LELLC to data. However, if DOE refuses advanced payments, this issue can be reconsidered by LELLC to ensure receipt of this grant.

Medium risks

3) Melcor modeling would improve results, but schedule and unavailability of Sandia support are prohibitive.
4) Relap5 models still require data.
    a. The TMI-2 Safety Analysis Report may be obtained from NRC by DOE
    b. TMI-1 analysis may be an option.
    c. TMI-2 data may be found in the literature.
5) Hydrogen generation models will not be exact.
    a. Models are unavailable for thermolysis.
    b. Melcor models are not planned for use.
    c. Frapcon and Fraptran are available for steady state and non-steady state hydrogen generation respectively.
6) CPU time is uncertain, and the schedule may be affected.
7) Subcontractor (Simutech) costs will not be confirmed until research training is in progress.

Table 1: Project Milestones[8]	
Milestone	**Planned Completion Date**
Year 1	
Paper 1: "Gas Pipeline Explosion Models"	Week 18
Paper 2: Gas Accumulation Events: Fatigue Cracks and Ruptures	Week 29
Year 2	
Paper 3: "TMI Normal Operations"	Week 63
Paper 4: "TMI Steam Line Failure and Reactivity Accident Validations"	Week 74
Paper 5: "Hydrogen Generation During TMI Meltdown Conditions"	Week 85
Paper 6: "Hamaoka Nuclear Reactor, Hydrogen Explosion Modeling"	Week 97
Paper 7: "TMI Nuclear Reactor, Hydrogen Explosion Modeling"	Week 100

Proposed Technologies, Methodologies, or Capabilities – Technology Gap

Discuss the degree to which proposed technologies, methodologies, or capabilities fill a known, existing gap in domestic nuclear technology capability and/or provide for improved deployment potential of advanced reactor designs.

The existing gap in domestic nuclear technology capability is clearly defined. Plant operators, engineers, and regulators are, in general, unaware that many nuclear power plant explosions have a common cause, and in many cases they are unaware that explosions occur in their facilities. Operating plants is dangerous when some of the fundamental principles of accidents are not understood. Plant personnel are incapable of completely safe operations when processes are not completely understood. In-process publications update years of research to capsize a fundamental belief that nuclear power plants are intrinsically safe. This research proves that explosions frequently occur during routine reactor operations, and further proves that most explosions during meltdowns can be prevented.

[13] Gas pipeline explosions are not the purpose of this research, but frequent gas pipeline explosions are described in the literature, and provide experimental data to serve as explosion model validations.

In short, the causes of nuclear reactor explosions were unknown prior to that research, and there is certainly an existing technology gap that needs to be filled. This research will provide required proof to the NRC for further discussions about reactor safety, which can ultimately stop explosions in nuclear reactors during normal operations, and prevent explosions when a meltdown happens again. Note that current opinions are that nuclear meltdowns cannot occur, but that same opinion was believed when the SL-1 meltdown occurred, when the Chernobyl meltdown occurred, when the TMI meltdown occurred, and when the Fukushima meltdowns occurred – meltdowns again occurred.

Technologies, Methodologies, or Capabilities - Commercialization

Discuss the degree to which the proposed technologies, methodologies or capabilities can be commercialized and applied by industry to improve construction, commissioning, and/or operations of advanced reactor designs.

This research will develop an overview of preventive actions for explosions in operating nuclear power plants, by investigating the well documented Three Mile Island meltdown accident. Since a single reactor will be investigated in detail during this research, additional work will be required for different reactor designs. This future work is outside the scope of this proposal, since the safety analysis for many reactors will be affected, and safety analysis is typically the responsibility of the utility that operates the plant. That is, LELLC will not be contracted for safety analysis or design work for these utilities. The goals of this research are to clearly understand the pertinent explosion processes to mitigate risks to nuclear reactors, reactor personnel and the general public. This explosions research can improve the commissioning and operation of advanced reactor designs, where technological advances and NRC regulation improvements will address safety concerns.

The technologies and methodologies that result from this research will have wide commercial applications, since the entire U.S. reactor fleet and other reactors around the world are affected by two significant explosion problems. The first problem to be commercialized will be the prevention of small scale explosions that occur during routine operations – venting may be available for some reactors and not available for others- investigation by utilities will be required. The second problem to be commercialized will be the modifications of emergency response procedures in nuclear plants – appropriate hydrogen venting techniques must be implemented, and this research will provide insights into emergency procedures and emergency planning. Although this research will have significant commercialization impact, LELLC does not expect, nor plan, to commercialize this research, since safety analysis functions are typically performed by the Operators/Utilities that are responsible for nuclear plants. Even so, a series of detailed technical reports will recommend specific guidance on the required methods to stop explosions, and model results will provide significant engineering insights.

Table 2: Decision Points and Success Criteria[8]

Decision Point	**Success Criteria**
Decide if explosion models are adequate.	Compare San Bruno piping damages to published catastrophic piping explosions.
Year 1 Assessment	Evaluate San Bruno explosion results.
Decide if piping fatigue failure models are adequate.	Compare Fluent fatigue model results to experimental SRS research.
Decide if loss of coolant and reactivity analysis are adequate.	Compare Parcs -Relap5 results to published NRC results for reactivity and steam piping accidents.
Determine if Hamaoka and TMI explosion analyses are adequate.	Compare Hamaoka piping explosion model to published accident photos of the exploded piping.
Final Assessment	Evaluate fatigue model, Hamaoka, steam piping accident, and reactivity accident.

Table 3: Risk Assessment Criteria / Risk Factors

		Consequence				
		1, Insignificant	2, Minor	3, Significant	4, Major	5, Severe
Frequency	5, Almost Certain	5 , Medium	10 , High	15 , Very High	20 , Extreme	25 , Extreme
	4, Likely	4 , Medium	8 , Medium	12 , High	16 , Very High	20 , Extreme
	3, Moderate	3, Low	6 , Medium	9 , Medium	12 , High	15, Very High
	2, Unlikely	2, Very Low	4, Low	6 , Medium	8 , Medium	10 , High
	1, Rare	1, Very Low	2, Very Low	3, Low	4 , Medium	5 , Medium

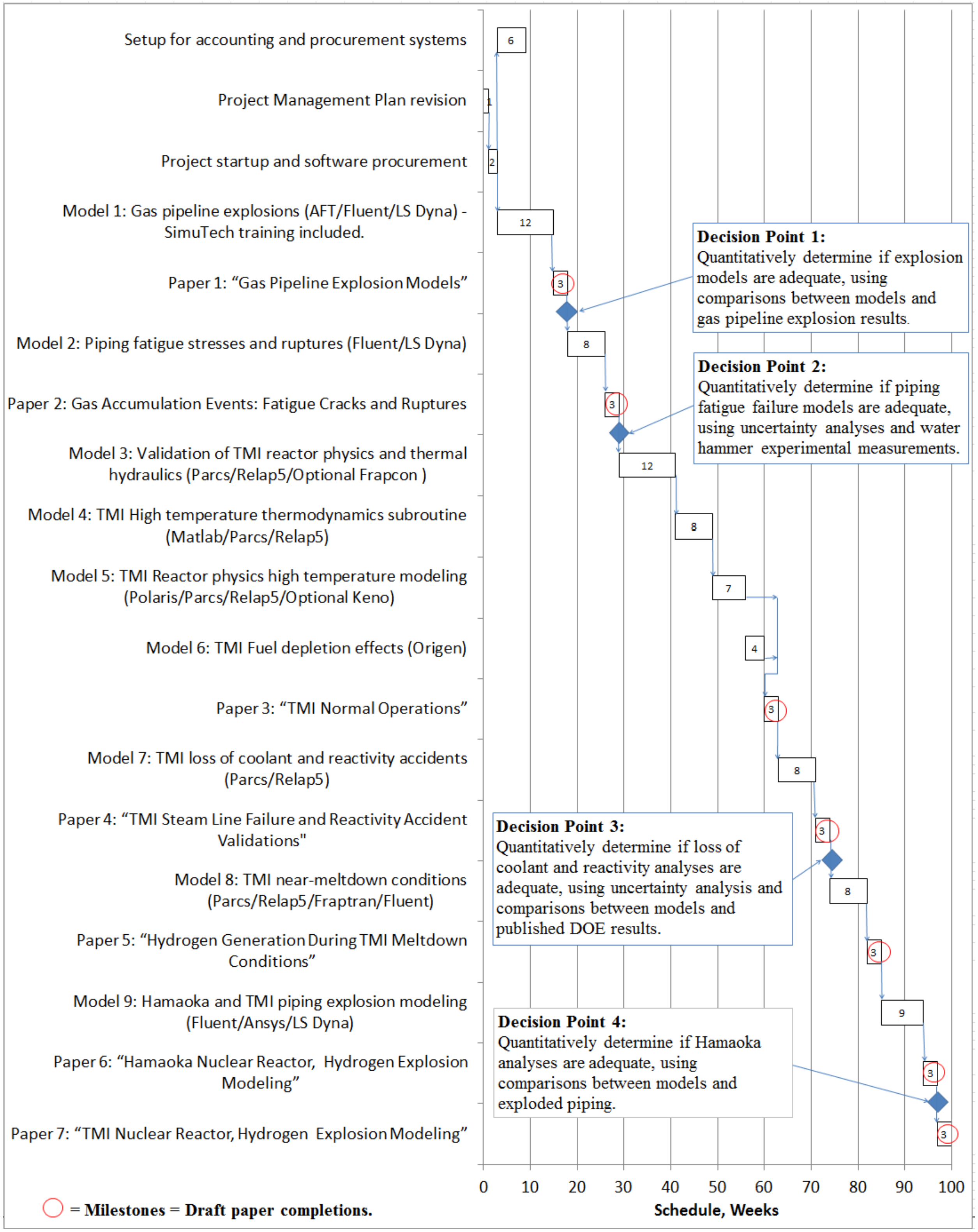

Figure 4: Project Schedule[8]

Table 4: Risk Matrix

No.	**Risks** (R01 -R07 are external risks - all other risks are project technical risks and project organizational risks)	Categories	Unmitigated Consequence	Unmitigated Probability	Unmitigated Risk Factor	Risk Responses	Mitigated Consequence	Mitigated Probability	Mitigated Risk Factor
R01	Large radioactive releases from explosions.	Technical	5	5	25	Mitigate: Preventive actions from this research will minimize large radioactive releases. ASME paper in publication to explain radioactive releases and stop imminent deaths. ASME and ANS papers were published to explain radioactive releases.	2	1	2
R02	Gas pipeline explosion.	Technical	5	5	25	Mitigate: Preventive actions from this research will minimize gas pipeline explosions and stop continuing deaths that occur every year. A gas pipeline explosion paper was published to explain pipeline explosions.	2	1	2
R03	Nuclear reactor meltdown.	Technical	4	5	20	Accept: No actions to prevent meltdowns during this research. However, TMI accident conditions will be modeled. Model scaling may be required for TMI. Predictions for the next nuclear reactor meltdown and explosion is in review for ASME publication.	4	5	20
R04	Gas pipeline cracks from explosions.	Technical	3	5	15	Mitigate: Preventive actions from this research will stop reactor piping damages and potential deaths (Published theory).	2	1	2
R05	Nuclear reactor system piping cracks from explosions.	Technical	2	5	10	Mitigate: Preventive actions from this research will stop piping explosions. Inaction results in continuing damages to the US nuclear reactor fleet plus potential damages to future reactors (Published by BHR Group).	2	1	2
R06	Water main breaks from fluid transients.	Technical	4	5	20	Mitigate: This research will improve previous recommendations in publication to stop multi-billion dollar U.S. damages due to fewer breaks, i.e., this rsearch will provide a better technical understanding of water main breaks. R. Leishear is the Project Manager for an in-process ASME standard on water hammer. Numerous papers and an ASME book have already been published on this topic. Risks reduced by earlier research.	2	1	2
R07	Lack of technology - New technical discoveries.	Technical	4	4	16	Exploit: New discoveries are an integral part of new research, where the full scope of research considered here has never been performed. Discoveries have already been published from this research, as part of an extensive education effort to support this research.	2	1	2
R09	Unavailabity of computer codes to model reactor startup from meltdown conditions.	Technical	5	3		Mitigate: There are no available codes that can model restart after a meltdown. Interrelated models will reduce this risk.	2	2	4
R13	Loss of R. Leishear. Research stops.	Resources	5	1	5	Mitigate: Successive, real time, publications will reduce the risk of lost research data. Others can continue through separate research in the event of a death. The probabilty of death during this research project is less than 5%.	3	1	3
R19	Thermal hydraulic model delays.	Schedule	4	3	12	Mitigate: TMI Reactor core models that were used in previous classes will again be used here. Also, the NRC provided a TMI-1 model for the rest of the reactor system, which needs to be verified for accuracy. Dr. Leishear will attend Matlab programming to facilitate NRC models.	2	2	4
R20	Fluent combustion model devlopment delays.	Schedule	4	3	12	Avoid: Simutech, a Fluent contractor, will provide specialized training for pilot scale modeling to expedite the schedule.	2	2	4
R21	LELLC combustion modeling results.	Schedule	5	2	10	Avoid: LELLC will procure Fluent, Ansys, LS Dyna, and AFT Impulse licenses to support this research wih full access to Fluent and AFT staff for technical consultations.	2	1	2
R22	LELLC reactor modeling results.	Schedule	4	3	12	Avoid: All required reactor software has been purchased, and required classes to operate this software have been attended.	2	1	2
R25	Fluent procurement.	Schedule	4	4	16	Accept: Advanced DOE payments are required to purchase Fluent software. LELLC will retain software ownership for subsequent research for potential future grants to further this research. Another option is to rearrange the schedule to ensure that funding is available from LELLC wages, where explosions understanding would be delayed. Thissecond option is not preferred, since a progressing explosion understanding will provide addtional insights into TMI modeling to ensure that TMI models are adequate. LELLC wil provide advance payment with 30 day reimbursement from DOE.	2	2	4
R27	Unavailable software to fully model TMI reactor meltdown to explosion sequence.	Quality Assurance	5	5	25	Mitigate: Relap5 and Fraptran will be used to model some hydrogen generation and hydrogen location at the time of the accident. Then, this output data will be input into Fluent. Extensive PI education and training was completed to ensure that selected models can successfully complete this research project to save lives and property.	2	1	2

R28	Software accuracy.	Quality Assurance	5	4	20	Mitigate: NRC and NQA-1 approved software will be used. Some model fidelity will be lost due to RANS simulations, but the cost for high resolution numerical models (DNS) approaches $1,000,000, which is outside the scope of this research and schedule. Accept the accuracy of RANS modeling.	2	1	2
R29	TMI Nuclear reaction modeling accuracy.	Quality Assurance	4	4	16	Mitigate: Parcs and Relap5 reactor data is available for TMI normal operating pressures and temperatures. High temperatures require additional modeling, where courses were attended to address this issue.	1	1	1
R31	Gas compression model accuracy since Relap5 does not adequately model gas compression.	Quality Assurance	3	5	15	Avoid: Data from Relap5 will be used as input to Fluent models for gas compression and combustion modeling.	2	2	4
R32	Validation of Parcs and Relap5 TMI models. Complete model validation cannot be performed.	Quality Assurance	3	5	15	Mitigate: Partial model validation for Relap5 and Parcs will be compared to NRC steam line break and reactivity models, which are published in the literature.	2	2	4
R36	Final explosion models cannot be fully validated.	Quality Assurance	4	4	16	Mitigate: Although model errors cannot be confirmed without experiment, Fluent, Ansys, and LS Dyna are accepted world-wide as competent computer modeling codes for combustion, sturctural response, and fluid flow. Gas pipeline explosion models can be validated through the evaluation of explosion craters, which are documented in the literature.	2	3	6
R39	Data loss due to viruses, hacking, or environmental office damages.	Quality Assurance	4	4	16	Miigate: Data backups will be routinely performed. Anti-virus protection installed on computers. Procure computer backup services in addition to flash drives.	2	1	2
R40	Lack of Quality Assurance.	Quality Assurance	3	4	12	Avoid: The LELLC PI has experience as a Quality Assurance Engineer, implementing NQA-1 requirements into plant procedures and employee performance.	1	1	1
R41	Simutech contract performance for LELLC.	Communications	3	2	6	Accept: SimuTech is a contractor service provider for Fluent products, which are required for this research.	3	2	6
R42	LELLC contract performance for DOE.	Communications	4	3	12	Sharing: Quarterly reports will be provided to DOE, as required by contract, for costs, schedule, risks, and technical reports in the form of draft conference publications.	2	1	2
R43	LELLC contract performance for DOE.	Stakeholder management	4	3	12	Mitigate / Avoid: Extensive PI experience with multiple project stakeholders at Savannah River Site / Savannah River National Laboratory.	3	1	3
R44	LELLC risk management.	Monitoring, controlling, and executing risks	4	3	12	Mitigate: A risk register will be maintained to monitor risks, and aappropriate decision points have been established in the schedule to control risks and implement risk responses.	2	2	4
R45	Cost overruns.	Cost management	4	3	12	Mitigate: Costs will be monitored during work performance and invoices will be provided on a 30 day cycle for DOE payments to LELLC and modeling and research, for LELLC training, an dfor Fluent procurement.	2	2	4
R46	Funding reserve analysis.	Cost management	4	3	12	Mitigate: DOE reimbursement will be paid within 30 days for software procurement, insurance payments, and accountant payments to ensure that money rerverves do not become a problem.	1	1	1
R51	Project failure to achieve expected results.	Project management	5	5	25	Mitigate: The overall risk assessment process ensures project success - success is better than failure. Failure of this project will result in continuing deaths and destruction.	2	2	4
R52	Scope change / Schedule delay .	Project management	4	4	16	Mitigate: Extensive PI experience in project management, cost estimating, and scheduling minimizes potential project risks. Attended Project Management Professional training to prepare for this contract. Change request method TBD.	2	2	4
R53	Computer crash.	Project management	4	3	12	Mitigate: Add budget to procure a second computer in the case of computer damage, e.g. crash, where this computer wll also be used to mitigate schedule risks if program run time is excessive.	1	1	1
R54	Project delays can cause cost and schedule overruns if decision points lead to findings that require additional research.	Project management	3	3	9	Mitigate: Add budget to procure software during Year 3, if schdule slips.	2	2	4

Relevance and Outcomes/Impacts[14]

Quite simply, this research will lead to the stopping of explosions in operating nuclear plants. The pursuit of nuclear reactor safety with respect to explosions is certainly in accordance with this FOA, and stopping nuclear power plant explosions stands out as a high priority for DOE[15]. Even so, this research

[14] *FOA requirement:* Detailed risk assessments, milestones, and schedule provide outstanding *clarity, completeness, and appropriateness of the Project Management Plan in establishing a credible project base and how the Statement of Project Objectives will be implemented and managed.* See SF424RR.

[15] *FOA requirement:* Prevention of fatalities is an overwhelming *anticipated benefit of the proposed work in comparison to current commercial and emerging technologies*, as an outcome of this first-of-a-kind research.

highlights the problem, and regulators and nuclear plant personnel and management will need to take action. Also, an understanding of reactor explosions can certainly affect advanced reactor selections. To date, explosion theory has been published but not accepted. This research will be a giant step toward gaining that acceptance in the engineering community, and stopping explosions at nuclear power plants.

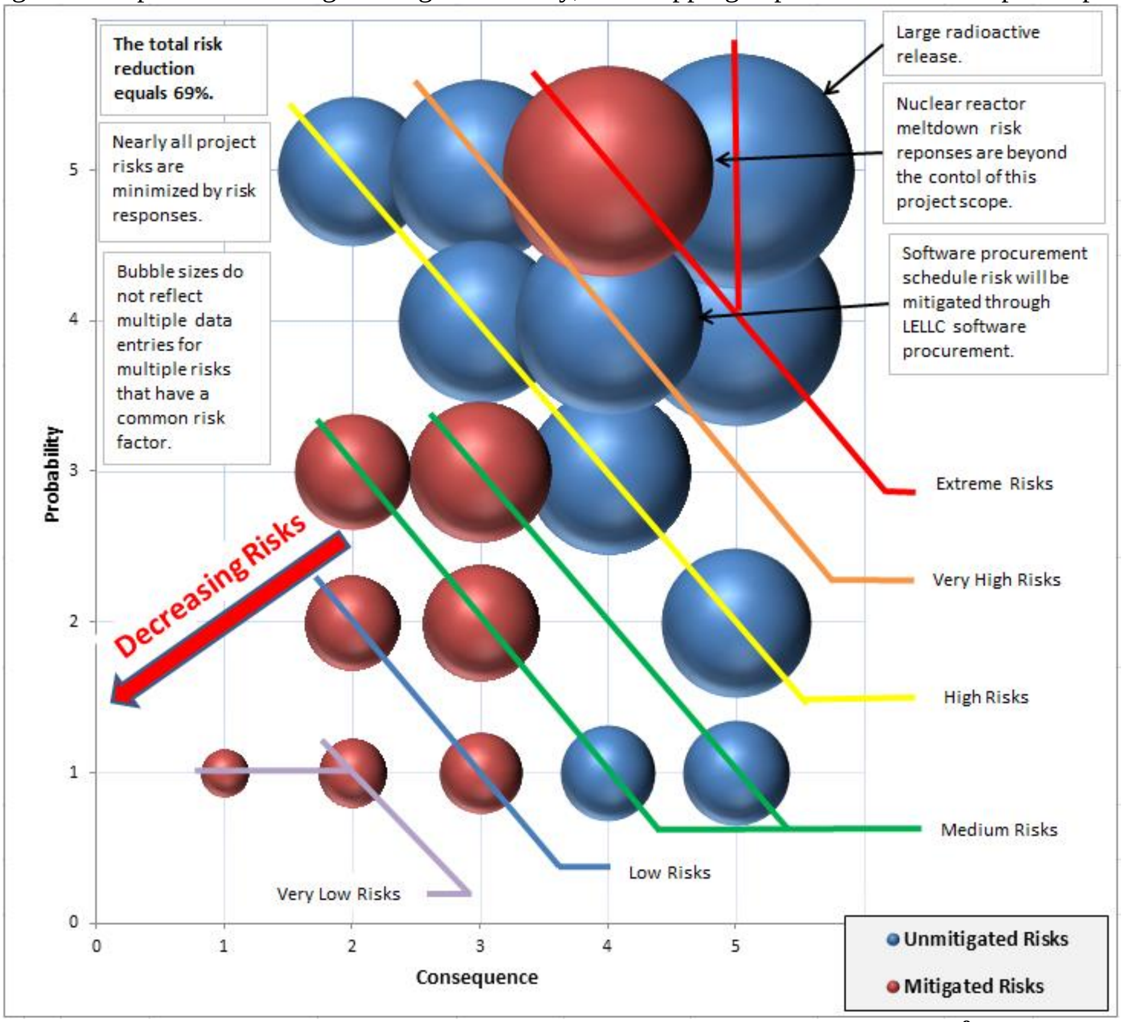

Figure 5: Reduction of Unmitigated Risks to Mitigated Risks[8]

CRITERION 2 – TECHNICAL AND MANAGEMENT CAPABILITY - MERIT REVIEW CRITERIA

LELLC Credentials, Capability, and Experience[16]

Discuss credentials, capabilities, and experience of key personnel, including the strength of the team to successfully accomplish the project.

Leishear Engineering provides services to troubleshoot existing fluid system problems or to complete new designs. In particular, difficult and seemingly insoluble fluid flow problems, pipe failures, and machinery failures can be resolved. Dr. Leishear has had the good fortune to earn an extensive engineering education and experience, which are coupled with an extensive hands-on technical background in the construction trades. His career has been dedicated to understanding all aspects of fluid machinery and fluid systems operations, as well as failure analysis of equipment, piping failures, and combustion.

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[16] FOA requirement: Dr, Leishear has impeccable *credentials, capabilities and experience as the key personnel* for this project.

The PI (R.A. Leishear, Ph,D, P.E.) has impeccable qualifications, capabilities and experience for this research. In his career before starting this research full time in January of 2016, Dr. Leishear had numerous accomplishments. Robert A. Leishear, PhD, P. E. is a Fellow of the American Society of Mechanical Engineers (ASME), a Consulting Engineer for Leishear Engineering, LLC, a licensed Professional Engineer in South Carolina, and a member of several ASME international piping and pressure vessel committees. He has traveled far from his days of walking on four inch I-beams, 300 feet in the air without fall protection, to his present position of a Doctor in Engineering. His wide range of skills developed along the way can be used as tools to fix your piping system and fluid flow problems to increase the success of industrial companies.

Dr. Leishear earned his Bachelor's degree in Mechanical Engineering from Johns-Hopkins University, parallel to completing a Journeyman Sheet Metal Mechanic's apprenticeship and welding school. While employed at Savannah River Site (SRS), he attended the University of South Carolina at night to earn his Masters and Doctoral degrees in Mechanical Engineering and has completed all of the classes required to earn a PhD in Nuclear Engineering – Dr. Leishear's Ph.D. advisor and Director of the University of South Carolina Nuclear Engineering Department provided a reference for this research (Past Performance file). While completing graduate research, he completed over a hundred Savannah River Site nuclear facility process engineer classes, electrician training, and ASME piping and pressure vessel design classes. All in all, he has one of the most extensive educations in the mechanical engineering industry.

Dr. Leishear's studies and accomplishments focused on fluid flow, piping design, vibrations, failure analysis, and fluid machinery, as well as explosions in piping systems. That is, his specialties are fluid, structural, and machinery dynamics, where he has worked as a research engineer for Savannah River National Laboratory, a Process and Plant Engineer for Savannah River Nuclear Solutions, and as a lead engineer for design, calibrations, compressors, mixing, pumps, and piping. In these positions, he earned tens of millions of dollars in cost savings, which are documented in his more than 80 publications.

These publications include an ASME text book, magazine articles, conference papers, and Honors journal papers. He has also taught advanced engineering classes throughout the country for the American Society of Mechanical Engineers. The ASME Press Manager provided a reference, where an ASME book is planned to be based on this research (Past Performance file of this FOA).

To capstone his troubleshooting successes, Dr. Leishear received several ASME awards for service, a dozen SRS corporate awards, and the Mensa Copper Black Award for Creativity for his research on explosions in nuclear facilities and offshore oil rigs. His future success can be your success as well.

Since leaving SRS in 2016, Dr. Leishear has worked full time on this research, with few exceptions. One exception was a troubleshooting job for the Pantex nuclear weapons plant, where that proprietary research was completely successful - the Senior Engineering Director for Pantex and Y12 provided a reference for this work (Past Performance file). For another exception, Dr. Leishear occasionally teaches five day ASME classes from his ASME textbook on fluid transients and piping failure analysis.

Other recent research was the basis for an ASME Journal paper (Leishear [21]). This research uses a dynamic stress theory that Dr. Leishear invented in the 2000's to explain piping fatigue failures. In particular, water main breaks have gone unresolved for more than a century, where the cause could not be identified by any engineer in the water industry. Thirteen billion dollars a year is the present estimated damage cost for North American alone, where water main breaks plague every industrial nation. He has determined the common mode failure cause for nearly all of the U.S. water main breaks, which pepper the newspapers and trade journals catastrophic piping failures that can collapse roadways. Without the use of the dynamic stress theory that Dr. Leishear invented, these water main breaks cannot be explained, where calculated static stresses are magnified times a dynamic load factor to find the actual dynamic stress.

Coincidentally, this dynamic stress theory is the basis of Dr. Leishear's ASME textbook and that theory is also applicable to the piping failures that occur in nuclear reactor piping systems due to explosions. In short, decades of successful engineering experience will be coupled with an extensive education to complete this research and make nuclear reactors safer to operate.

LELLC Demonstrated Past Performance[17]

Discuss demonstrated past performance of the Applicant and its proposed subrecipients (not required for FFRDC/NL) in managing projects that meet project objectives, within budget and on schedule. (Note that in evaluating this criterion, DOE reserves the right to use information submitted with the application as well as past performance information obtained from any other source(s).)

Dr. Leishear has served as the PI on projects at the Savannah River National Laboratory (SRNL). His responsibilities as lead researcher on those projects included parts specifications, scheduling, cost estimates, and engineering design. Each of those projects was completely successful, where all risks were correctly recognized at the project onsets. Those projects varied in value from several hundred thousand dollars to a million and a half dollars. Dr. Leishear's immediate supervisor for SRNL pilot-scale research provided a reference for this research (Past Performance file)[18].

For one project, the customer (Hanford) not only received ground breaking research results, but Dr. Leishear published those results in an ASME Journal with joint authorship from Hanford and SRS Engineering staff (Leishear [24]). On another project completed for $1,500,000, Dr. Leishear modeled a one million gallon tank with a pilot-scale 10 feet diameter tank. He performed the experimental research while directing and leading the Fluent finite element analysis modeling. Again the results met customer expectations with ground breaking research, and results were jointly published with the customer (SRS Operations and Engineering staff) in an ASME Mechanical Engineering Magazine article and a Journal paper was published with SRS researchers (Leishear, et al [25-26]).

Dr. Leishear has also worked on numerous other projects throughout his career as the lead designer and scheduler for multiple projects. For one of those projects, he was responsible for the design and procurement of three pumps at a cost of $1,500,000 each. Historically, these pumps had a very short life where the mechanical seals failed due to vibrations, and Dr. Leishear performed research to invent a theory to improve the life of those pumps, wrote a pump specification to buy the pumps, and participated in a Six Sigma evaluation to document a $27,000,000 cost savings for SRS (Leishear [27]) – a Senior Vice President of Savannah River Remediation at SRS provided a reference for this research (Past Performance file). Dr. Leishear always meets budget, and frequently completes projects ahead of schedule, through hard work and long hours where 50 to 70 hour work weeks have been standard throughout his career.

Numerous references to support Dr. Leishear's project management and technical abilities are supplied in the Past Performance file.

LELLC - Type/Description of Facilities

Computer codes will be run at the LELLC office on a four core computer. A second computer will be purchased if schedule requires such an action.

Information, data, plans, or drawings

All of the required information to perform this research is documented in previous research papers with the exception of some design details for the TMI piping that are required for TMI modeling, as noted above in the Risk Summary.

Data Reports

Listed as schedule milestones, there will be seven required reports at a minimum. In fact, one additional paper on Gas Pipeline Explosions is in process for the Annual Combustion Institute Convention in 2020, and attending this conference will be an opportunity to discuss the Leishear Explosion Theory for the first time in an audience of combustion experts. Between the peer reviews for

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[17]*FOA requirement:* LELLC has excellent and outstanding performance with respect to *demonstrated capability and experience of the Applicant and its participating organizations in managing projects that meet project objectives, within budget and on schedule,* and *exceptional clarity, logic and effectiveness of project organization … to successfully complete the project.*

[18] Employer references for this research were provided last year while experimental research was pursued and research publications were continued. The ground work for this research is now complete.

this paper and comments at the Convention, Dr. Leishear will receive excellent feedback on his combustion research. Another paper is in process for the National Association of Corrosion Engineers Annual Conference, and this paper concerns the reduction of fatigue properties when pipes are grit blasted for coating adherence. This second paper is directly applicable to fatigue failures of nuclear reactor piping.

SimuTech Credentials, Capability, Experience, and Past Performance

Although SimuTech is not a contractor for this research, Dr. Leishear will attend classes at their New York facility to facilitate his use of Fluent, Ansys, and LS Dyna. The use of these codes and complex subroutines is essential to the success of this research. This issue was identified as an important risk in the project risk assessment (Risks r16. 20, R41, and R48), and the mitigation action for this risk is attendance in this one-on-one specialized tutorial. Detailed discussions between SimuTech staff and LELLC concluded that this training is the appropriate method to ensure project success.

The SimuTech Group, a Fluent/Ansys contractor, is a team of "trusted advisors who help clients gain insight to improve product efficiency, reliability, and performance through sales, consulting, tech. support, and training using ANSYS engineering simulation software and physical testing. We're proud of our 35-year relationship with ANSYS as part of the first cohort of Channel Partners, the first ANSYS Elite Channel Partner in North America, and the 2017 Americas Channel Partner of the Year. The company employs "over 100 employees, nearly half are engineers, most holding Master's or PhD degrees, Eight offices throughout USA and Canada serving over 3,000 customers, ANSYS software sales, ANSYS support services including technical support and training, Engineering simulation consulting services, Turbomachinery and physical testing support and services. Net Promoter Score (NPS) of 82.4 for ANSYS technical support and 94 for consulting in 2018, ANSYS 2016 Presidents Club - Achievement Award."

RESEARCH SUMMARY

This research will save lives, and lives will be lost if this research is not performed. Leishear Engineering, LLC will earn wages for research, but future profits are not expected to be realized from this research by LELLC. This research is simply the right thing to do.

I have been asked the questions, why do I care if the government does not care, if I do not expect to receive future contracts from this research, and if I am unlikely to receive any accolades for this research. The answer is simple. "I, Robert Leishear, have the ability to save lives, and I therefore have a responsibility to use my unique skills to save lives. In the absence of this belief, the cause of nuclear reactor explosions and gas pipeline explosions would still be unknown, and lives would continue be lost unnecessarily." This proposal presents an extraordinary opportunity for DOE to step up and save lives.

Although LELLC does not plan to directly commercialize this research, the results of this research will enable Reactor Operators to operate reactors more safely and economically – a tremendous commercial benefit. This research will provide recommendations based on fundamental physics to appropriately monitor reactor operations to measure small scale explosions, will further provide recommendations to stop these small scale explosions, and will provide recommendations to stop explosions that follow meltdowns. A parallel goal is to provide sufficient data to warrant the change of NRC regulations to ensure safer reactor operations.

APPENDIX A: BIBLIOGRAPHY AND REFERENCES CITED

Several hundred references support the following publications.

[1] Leishear, R. A., 2010, "A Hydrogen Ignition Mechanism in Nuclear Facility Pipe Systems", ASME Pressure Vessel and Piping Conference, Society of Mechanical Engineers, N.Y., N.Y., pp. 907-912.

[2] Leishear, R. A., 2013, Explosions: A Fresh Look at Chernobyl, Three Mile Island, the Gulf Oil Spill, and Fukushima Daiichi, Mensa World Journal, Mensa International Limited, Caythorpe, U.K., 1 p.

[3] Leishear, R. A., 2013, "Pipeline Explosions, A New Theory, ASME Mechanical Engineering Magazine, American Society of Mechanical Engineers, N.Y., N.Y., p. 8.

[4] Leishear, R. A., 2013, A Hydrogen Ignition Mechanism in Nuclear Facility Pipe Systems, ASME Journal of Pressure Vessel Technology, American Society of Mechanical Engineers, N.Y., N.Y., pp. 1-5.
[5] Leishear, R. A., 2013, From Water Hammer to Ignition, The Spark That Ignited Three Mile Island Burst from a Safety Valve, Mechanical Engineering Magazine, ASME, N.Y., N.Y., pp. 46-49.
[6] Leishear, R. A., 2017, "Nuclear Power Plant Fires and Explosions, I, Plant Design and Hydrogen Ignition", Pressure Vessels and Piping Conference, ASME, N.Y., N.Y., 9 pps.
[7] Leishear, R. A., 2017, "Nuclear Power Plant Fires and Explosions, II, Hydrogen Ignition Overview", Pressure Vessels and Piping Conference, American Society of Mechanical Engineers, N.Y., N.Y., 11 pps.
[8] Leishear, R. A., 2017, "Nuclear Power Plant Fires and Explosions, III, Hamaoka Piping Explosion", Pressure Vessels and Piping Conference, American Society of Mechanical Engineers, N.Y., N.Y., 9 pps.
[9] Leishear, R. A., 2017, "Nuclear Power Plant Fires and Explosions, IV, Water Hammer Ignition Mechanisms", Pressure Vessels and Piping Conference, ASME, N.Y., N.Y., 7 pps.
[10] Leishear, R. A., 2017, "Nuclear Power Plant Fires and Explosions, Accident Overviews", Pressure Vessels and Piping Conference, American Nuclear Society, N.Y., N.Y., pp. 1-4.
[11] Leishear, R., 2019, "The TMI-2 Explosion", ANS Nuclear News Magazine, LeGrange Park, Il., 1 p.
[12] Leishear, R. A., 2019, "The Autoignition of Nuclear Power Plant Explosions", Journal of Radiation Science and Technology, American Society of Mechanical Engineers, N.Y., N.Y., 22 pps. (in publication).
[13] Kuzentsov, M., Yanez, J., Grune, J., Friedich, A., Jordan, T., 2015, "Hydrogen combustion in a flat semi-confined layer with respect to the Fukushima Daiichi Accident", Elsevier Press, Waltham, Ma., pp.36-48.
[14] Henrie, J.O., and. Postma, A.K., 1983, "GEND-INF-023, Analysis of the Three Mile Island Unit 2 Hydrogen Burn," The Electric Power Research Institute, 20 pp.
[15] Leishear, R. A., 2019, "Nuclear Power Plants are Not So Safe: A Question of Ethics", Journal of Radiation Science and Technology, ASME, N.Y., N.Y. 11 pps.(in process).
[16] Leishear, R. A., 2018, "Pump Startups Ignite Nuclear Power Plants, History, Law and Risks", British Hydraulic Research Group, Cranfield, Bedfordshire, United Kingdom, 16 pps.
[17] Leishear, 2015, PRE-GI-015, Hydrogen Fires and Explosions in Nuclear Reactors, ML15245A508, US Nuclear Regulatory Commission, Washington, D.C., 12 pps.
[18] Boyce, 2015, T. H., "Response to PRE-GI-015: ML15191A397, ML15191A398, ML16007A181, ML16007A182, ML16063A320", US Nuclear Regulatory Commission, Washington, D.C. pp. 15 pps.
[19] Leishear, 2013, *Fluid Mechanics, Water Hammer, Dynamic Stresses, and Piping Design*, ASME Press, American Society of Mechanical Engineers, N.Y., N.Y., 448 pps.
[20] Leishear, 2015, *Supplement to Fluid Mechanics, Water Hammer, Dynamic Stresses, and Piping Design*, ASME Press, American Society of Mechanical Engineers, N.Y., N.Y, 118 pps.
[21] Leishear, 2019, "Water Hammer Causes Water Main Breaks", Journal of Pressure Vessel Technology, American Society of Mechanical Engineers, N.Y., N.Y. 22 pps. (in publication).
[22] Leishear,, "Grit Blasting for Coatings Accelerates Piping and Structural Failures", Empowering Pumps and Equipment eMagazine, Tuscaloosa, Al., 2 pps.
[23] Leishear, 2019, "The Primary Cause of Oil and Gas Pipeline Explosions", Empowering Pumps and Equipment eMagazine, Tuscaloosa, Al., 2 pps.
[24] Mass Transfer Coefficients for a Non-Newtonian Fluid and Water With and Without Anti-foam Agents", 2010, Leishear, Restivo, Sherwood, Guerrero, ASME, J Fluids Eng- Trans ASME, 21 pps.
[25] Leishear, R. A., Lee, S. Y., Poirier, M. R., Fowley, M. D., and Steeper, T. J. , 2012, "Comparison of Experiments to CFD Models for Mixing Using Dual Opposing Jets in Tanks With and Without Internal Obstructions", J Fluids Eng- Trans ASME, 21 pps.
[26] Leishear, Lee, Stefanko, Fowley, Poirier, Steeper, Ervin,Van Pelt, Harp, Giddings, 2013, "CFD and Safety Factors", ASME, Mechanical Engineering Magazine, pp. 44-47.
[27] Leishear and Stefanko, 2005, "Relationship Between Vibrations and Mechanical Seal Failures in Centrifugal Pumps", International Mechanical Engineering Congress and Exposition, ASME, 8 pps.

THE AUTOIGNITION OF NUCLEAR POWER PLANT EXPLOSIONS

Robert A. Leishear, Ph.D., P.E.
ASME Fellow, NACE Senior Internal Corrosion Technologist, Journeyman Sheet Metal Mechanic
Leishear Engineering, LLC

Brunsbuttel Piping Explosion

Fukushima Fires Following Explosions

Submitted to the DOE, Office of Nuclear Energy, 11/09/2019.

COORDINATION AND MANAGEMENT PLAN

Applicant, Principal Investigator: Robert A. Leishear, Ph.D. P.E., ASME Fellow, Leishear Engineering, LLC, Email - Leishear @aol.com, Website – leishearengineeringllc.com, 803-641-6753

Process for making decisions on scientific/technical direction

Decisions for the technical direction of this project will be provided by Dr. Robert A. Leishear, since he is the sole researcher for this project. Decision points have been identified in the project schedule to identify the key decisions required to execute this project, and other evaluations will be performed as applicable throughout this project. These decisions will be reported to DOE in a quarterly status report for this research.

PIs' roles and administrative, technical, and scientific responsibilities for the project

The PI, Dr. Robert Leishear, Ph.D., P.E., will provide all technical and scientific direction for this project, based on his qualifications and experience. As discussed in detail in the Past Performance file, he invented the applicable theory for this research, and has spent thousands of hours performing volunteer research in preparation for this phase of the research. Dr. Leishear will perform all computer modeling and analysis required for this research. Peer review comments from Conference publication reviewers will be resolved in accordance with Conference policies.

Administrative responsibilities for this project will be shared by R. Leishear and J. Leishear. Janet Leishear will be responsible for budgets and payments, and Dr. Leishear will be responsible for scheduling and reports.

PIs' modeling responsibilities

Model 1: Gas pipeline explosions. These models are essential to provide a clear understanding of the combustion processes that are related to piping explosions. Both internal and external explosions and fire processes need to be better understood, and gas pipeline explosions are far better documented than nuclear power plant explosions. Accordingly, a gas pipeline explosion leads the modeling investigation. Specifically, the San Bruno explosion will be investigated, where a series of papers are in process to background this gas pipeline explosion, as noted below under Publications. Based on Dr. Leishear's previous research, approximate combustion properties will be utilized, where future research to investigate pertinent combustion fundamentals will be recommended from this research.

Model 2: Piping fatigue stresses and ruptures; These models are based on previous fluid transient research, and provide a better understanding of how pipes crack, and this knowledge can then be applied to pipe cracks due to explosions.

Model 3: Validation of TMI reactor physics and thermal hydraulics; These models can be directly compared to the research results of others, where a competent model of Three Mile Island (TMI) operations is required to continue research.

Model 4: TMI High temperature thermodynamics subroutine; *Model 5*: TMI Reactor physics high temperature modeling; These models are required to continue the TMI models for explosion evaluation.

Model 6: TMI Fuel depletion effects; These models are required to confirm that fuel depletion effects have minimal impact on the explosion investigation.

Model 7: TMI Loss of coolant and reactivity accidents; *Model 8*: TMI near-meltdown conditions; These models validate TMI models.

Model 9: Hamaoka and TMI piping explosion modeling. These models will provide the end result of this research, which will consist of publications and the following supporting animations.

- TMI fluid flow to show where hydrogen and oxygen will accumulate in the TMI reactor cooling water system.
- Combustion and explosion in the Hamaoka piping system.
- Combustion and explosion in the TMI piping for Gas Accumulation Events.

- Combustion and explosion in the TMI piping system for post-meltdown explosions.

Publications

There are a minimum of 7 publications required to report the project research results of this research. These publications will document modeling results and supporting analysis. Papers are planned to be published at ASME and Combustion Institute conferences (tentative publication venues). Papers are listed as follows.

Paper 1: “Gas Pipeline Explosions”, R. Leishear, Combustion Institute;
Paper 2: “Gas Accumulation Events: Fatigue Cracks and Ruptures”, R. Leishear, Combustion Institute;
Paper 3: “TMI Normal Operations”, R. Leishear, ASME;
Paper 4: “TMI Steam Line Failure and Reactivity Accident Validations”, R. Leishear, ASME;
Paper 5: “Hydrogen Generation during TMI Meltdown Conditions”, R. Leishear, ASME;
Paper 6: “Hamaoka Nuclear Reactor, Hydrogen Explosion Modeling", R. Leishear, ASME;
Paper 7: “TMI Nuclear Reactor, Hydrogen Explosion Modeling”, R. Leishear, ASME.

There are also 6 pertinent publications currently in process, which are listed as follows.

”Nuclear Power Plants are Not So Safe: A Question of Ethics”, R. Leishear, ASME Journal of Nuclear Engineering and Radiation Science (In review);
”The Fluid Transient Disaster”, R. Leishear, ASME, 2020, Pressure Vessel and Piping Conference (Abstract submitted);
”The Primary Cause of Gas Pipeline Explosions, I, The San Bruno Explosion”, R. Leishear, ASME, 2020, Pressure Vessel and Piping Conference (Abstract submitted);
”The Primary Cause of Gas Pipeline Explosion, II, The Carlsbad Explosion”, R. Leishear, ASME, 2020, Pressure Vessel and Piping Conference (Abstract submitted);
”The Primary Cause of Gas Pipeline Explosions, III, An Accident Overview”, R. Leishear, ASME, 2020, Pressure Vessel and Piping Conference (Abstract submitted);
“Fatigue Strength Reduction Due To Grit Blasting for Coating Adherence”, R. Leishear, National Association of Corrosion Engineers, 2020 Conference (In review).

PIs’ reporting responsibilities

The PI is responsible for reporting the technical aspects and conclusions of this research, but more importantly is responsible to provide recommendations for future research and any actions that can be taken by reactor Operators to ensure reactor safety. He is also responsible to provide any recommendations that will improve NRC regulations to promote safe nuclear power plant operations. To provide these recommendations reports should include comprehensive discussions of modeling techniques, selected model parameters, model types, and limitations of modeling. The report format will be in the format of ASME, ANS, or Combustion Institute conference publications, as applicable. Applicable computer codes may be added as Appendices to DOE reports, but will not be added to Conference publications.

Intellectual property issues

There are no expected intellectual property issues. All research will be initially reported to DOE in draft, publication formats. Subsequent Conference and Journal publications will report this research to the engineering public, following peer reviews during the publication process. Some publications will be completed before the project ends and some will be published after this project is complete. Publications that are complete before project completion will be provided to DOE.

Communication plans

A quarterly progress report will be provided to DOE. Also, any unforeseen technical or administrative issues that have a significant project impact will be reported to DOE as soon as possible. Quarterly reports will assess cost, schedule, contract performance, and will include technical reports as they are available.

Procedures for resolving conflicts

Since there is only one researcher, potential conflicts consist of technical issues that may arise from decision points in the schedule, technical issues that may arise from computer modeling implementation, or schedule and cost concerns that may arise. A comprehensive risk assessment was performed as part of the Project Management Plan to identify potential project schedule, technical, and budget conflicts. Any such issues will be brought to the attention of DOE as soon as possible.

THE AUTOIGNITION OF NUCLEAR POWER PLANT EXPLOSIONS

Robert A. Leishear, Ph.D., P.E.
ASME Fellow
NACE Senior Internal Corrosion Technologist
Journeyman Sheet Metal Mechanic
Leishear Engineering, LLC

Nuclear Power Plant Explosions Can Be Stopped

Submitted to the DOE, Office of Nuclear Energy, 10/30/2019.

Contents

PAST PERFORMANCE

Applicant, Principal Investigator: Robert A. Leishear, Ph.D. P.E., ASME Fellow, Leishear Engineering, LLC, (LELLC) Email - Leishear @aol.com, Website – leishearengineeringllc.com, 803-641-6753

LEISHEAR ENGINEERING, LLC

EXECUTIVE SUMMARY

Leading many DOE facility projects, Dr. Leishear has met or exceeded schedules and budgets with extremely successful results, where he worked as a Fellow Engineer using DOE business and regulatory requirements for decades. Dr. Leishear's past performance and education prove his ability to manage DOE projects of similar size, scope, and complexity with respect to this research proposal. In particular, he has managed multi-million dollar projects, and while leading those projects he invented and published new theories on demand to complete innovative research. Some of his new theories are detailed in the Project Narrative File, i.e., the Leishear Explosion Theory, The Leishear Stress Theory, water main break theory, and grit blasting fatigue theory. His ability to manage projects was clearly demonstrated at two separate companies located at Savannah River Site (SRS), where these companies include Savannah River National Laboratory (SRNL) and Savannah River Remediation (SRR). In short, he has dedicated a major part of his life to ensuring project success to prevent fatalities, by inventing a one-man explosion theory. There is a problem, and it can be fixed.

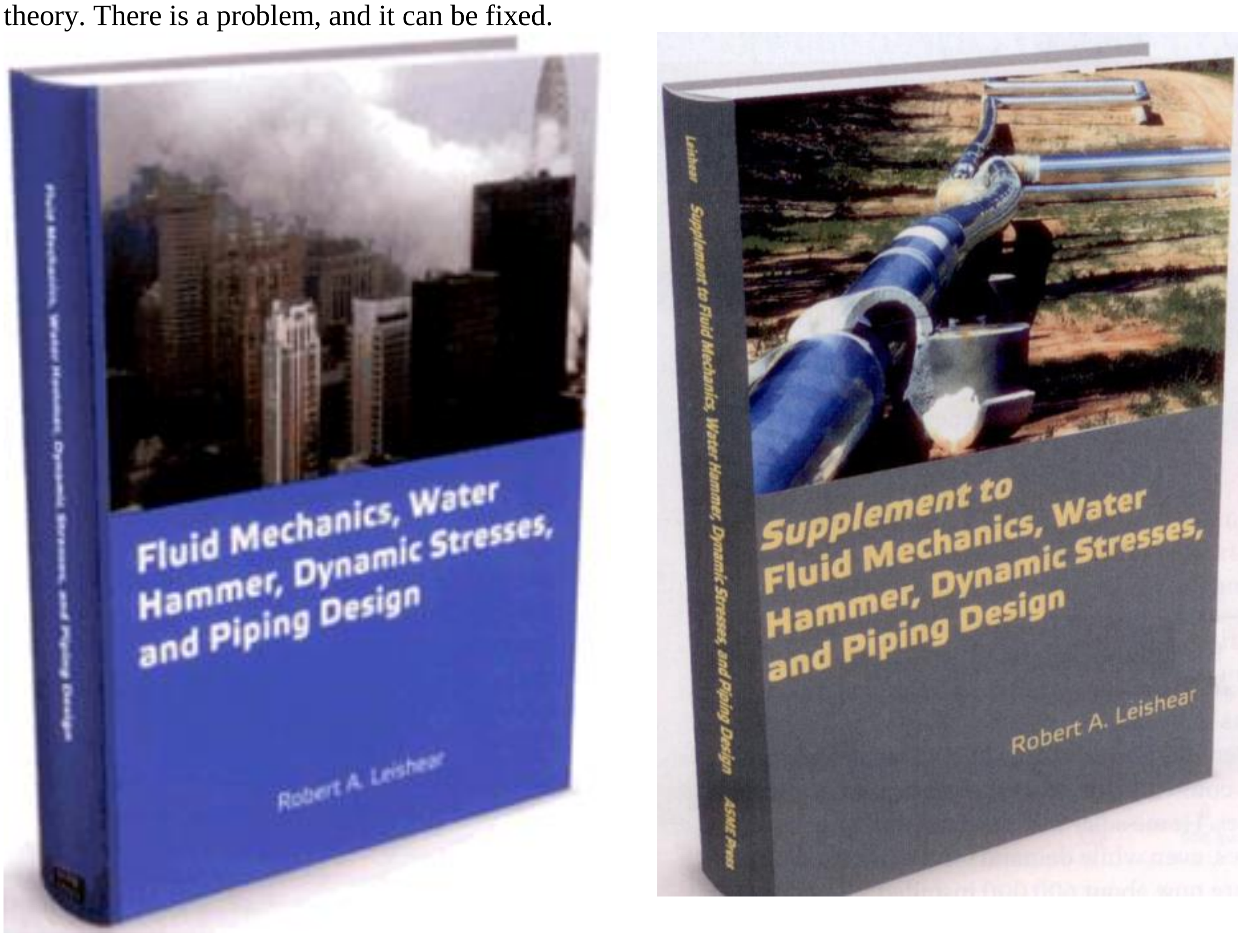


Figure 1: ASME Textbooks That Document the Leishear Stress Theory

At SRNL, Dr. Leishear worked as a Principal Investigator on complex, innovative research projects valued up to $1,500,000. These projects typically employed three to twelve laboratory personnel for engineering and technical support to build equipment and evaluate data. Dr. Leishear was responsible for engineering design, new theory as required, experimental test methods, procedures, daily safety meetings, and project management, i.e., cost, schedule, safety, and quality assurance.

As a Project Engineer and Test Engineer at SRR, Dr. Leishear managed schedule, costs, and innovation for multiple projects with values up to $4,500,000. These projects varied in size from a few employees to as many as fifty employees, where multiple organizations were involved in the project, i.e., operations, engineering, maintenance, quality assurance, radiation protection, industrial hygiene, and safety analysis.

Although Dr. Leishear incorporated Quality Assurance into all DOE contractor projects that he managed, he has dedicated experience as a Quality Assurance Engineer. Specifically, he implemented NQA-1 procedures into the SRNL Calibrations Laboratory for pressure and vacuum equipment calibrations.

With respect to safety, all projects at SRS required a safety discussion at the beginning of all meetings. SRS consistently earns safety awards for their safety culture, and Dr. Leishear's 24 years of service to SRS intrinsically carries this safety culture into Leishear Engineering, LLC (LELLC).

In fact, when LELLC contract work was performed for the Pantex nuclear weapons plant, Dr. Leishear repeatedly initiated safety talks before any field work, or walk-downs, were started for that contract. Additionally, Dr. Leishear served as a Shift Technical Engineer at SRR, where his primary responsibility was to implement the safety basis and ensure safe operations during his rotating shift position. To augment this safety experience, he also served as a Safety Analysis Engineer for radioactive packaging equipment to be transported on railways and roads. For this proposed contract, all computer research will be performed in an office, where safety is a major concern as well. As a matter of fact, this entire project is focused on safety and the prevention of loss of life.

Working on a Nuclear Engineering Ph.D., Dr. Leishear has studied an extensive array of courses in nuclear engineering, nuclear engineering law, nuclear reactor computer design codes, corrosion, radiology, and combustion engineering. These courses provide solid preparation for this proposed research, and he has worked full-time performing voluntary research for the past several years. In fact, Dr. Leishear's education is a crucial performance metric to ensure project success, where his extraordinary educational accomplishments are surpassed by few engineers or scientists - anywhere.

Integral to his projects and education, Dr. Leishear published more than 85 publications that included Conference papers, Honors Journal publications, magazine articles, newspaper articles, and an ASME (American Society of Mechanical Engineers) engineering textbook. Documentation of his successes and project management ability are provided here as Letters of Recommendation (Appendix A) from management staff. Wyatt Clark, a Vice President at SRS, employed Dr. Leishear as a consultant over many years at SRS, where Dr. Leishear earned $50,000,000 in cost savings for Mr. Clark, and $25,000,000 of those savings were documented in a Six Sigma project. Introduced through service on an ASME B31.3 piping committee, Brad Walker, an Engineering Director at Pantex and Y12, contracted Dr. Leishear to solve a 17 year long failure problem at Pantex. Dr. Leishear solved much of the problem during his first week of this proprietary contract, and the remainder of that three month troubleshooting project was completely successful. Billy Giddings was Dr. Leishear's immediate manager at SRNL, where Dr. Leishear published new theories on mixing, mass transfer, and robotics from his research. Mary Grace Stefanchik is the ASME Press Manager, who contracted Dr. Leishear to write two engineering text books on fluids and piping failure analysis. Finally, Dr. Knight is the Director of the Nuclear Engineering Department at the University of South Carolina, and he serves as the advisor for Dr. Leishear's Ph.D. research, which will document the work performed as described by this proposal, and this Ph.D. will also document all other supporting research to date. This comprehensive Ph.D. Dissertation will prove the technical basis to change the nuclear industry to stop nuclear power plant explosions.

To be provided after proposal submission, South Carolina Congressmen agreed to provide Letters of Commendation. Dr. Leishear met with Representative Joe Wilson and the staff of Senators Lindsay Graham and Tim Scott to discuss his concerns with respect to nuclear power plant safety and explosions. They acknowledged Dr. Leishear's safety concerns and commended his volunteer efforts to improve our country.

In short, past performance demonstrates that the applicant has demonstrated successful experience/past performance, knowledge, and understanding of the business and regulatory requirements for projects of similar size, scope and complexity in achieving project technical success within budget and on time with no significant safety and quality issues. Leishear Engineering is discussed in detail below to prove an expectation of success. Details to document performance follow, and present experience, references, and educational courses, which include Project Management Professional classes that were attended to improve the performance of this contract.

THE DEFINITION OF PAST PERFORMANCE

According to recent DOE iFOA training, past performance does not equal experience, it equates to the ability to meet budget and schedule, but most of the following discussions are related to experience for a very good reason. Much of Dr. Leishear's experience was performed as a volunteer at great financial and personal cost, for the sole purpose of ensuring that research proposed here can be completed on schedule and within budget. Accordingly, each section below that describes performance and experience will be followed by a short discussion of how the schedule and budget of this project are directly affected. In other words, budget and schedule hinge on past performance to ensure project success.

A PERSONAL STATEMENT FROM DR. ROBERT A. LEISHEAR

Budgets and schedule are measures to judge the success of a project, but skill and tenacity are the reins that drive success. Over the decades of my career, I have salvaged many projects that were resolved to failure. Budget had long been overrun, and schedules had long been abandoned. Engineers and management gave up and assumed that problems could never be resolved. Stepping into the disillusionment of others, unique skills that I have are an extraordinary background and a genius IQ to apply that background. These are the tools that I use to see the solution to problems that others cannot fathom. Perhaps this statement may seem arrogant, but I work extraordinarily hard to be good at what I do. I troubleshoot problems and invent new theory to target solutions for incredibly complex problems. I step forward to solve problems that seem insoluble. I do not quit when the problem seems overwhelming. These are the attitudes that bind schedule and budget to forge success. Although I held many different positions at SRS, let me summarize some of my accomplishments, which all required routine budget and schedule management.

When I first started at Savannah River Site 28 years ago, there was a leak of radioactive Tritium into the Savannah River that made the newspapers. Radioactive Tritium had gone downriver to Savannah, tritium release to the air was genuine concern, since Trtitium is a strong carcinogenic inhalant, and the leak needed to be controlled. This problem was a big deal on New Year's Eve, when most of the engineering staff had already gone home. Only the new guy was there to react to the crisis. I worked 18 to 20 hour days to design and build an emergency pumping station to transport Tritiated water from tanker trucks to a nuclear waste storage tanks. The project was a success, and 250 people were invited to lunch to celebrate, and I received an SRS award.

Subsequently, I became aware of four parallel pumps that required maintenance 24 hours a day, seven days a week for twenty years. Many engineers failed, but I offered to work on the problem. I spent two months to figure it out. The piping attached to the pump vibrated resonantly at the 560 Hz frequency of the electricity, and the vibrations destroyed the mechanical seals. I stiffened the foundation, changed the resonant frequency of the pumps, and the pumps did not experience another failure. My work was published as new theory, and today my theory is common knowledge in the pump industry. My coworkers and I received SRS awards.

In another case, I offered to work on four compressors that cost $1,000,000 per year in maintenance. I modified the compressor controls and corrected resonant air pulsations to reduce repairs by an order of magnitude – there is only so much that could be done with a poor design.

For long shaft pumps that are used to mix nuclear waste to control hydrogen generation for explosion prevention, I developed a new failure theory to explain pump failures, which occurred for decades. My theory was published and still serves as guide throughout the pump industry. As a result of this research, I was tasked to successfully lead and manage a 4.5 million dollar pump project.

I also worked on a robotic arm that was designed by others. It did not work properly. When the multi-million dollar project moved into disarray, I was given full rein of the project to solve the problem – success – results published – I received an award.

I managed several different projects as a PI at Savannah River National Lab (SRNL) with values up to 1.5 million dollars, and published numerous papers from SRNL research for two phase flow testing, mass transfer testing, and testing for mixing of liquids and solids.

Parallel to these accomplishments, I invented the Leishear Stress Theory to explain why pipes break due to water hammer. An ASME book summarized this research, which is a precursor to understanding explosions in nuclear power plants. Twenty one of my 85+ publications since 2002 were related to water hammer. Two years ago, I performed a contract at the Pantex nuclear weapons assembly plant. Their engineering staff had 17 years of failures and fire alarms three times a week. In my first week on site, I reduced the fire alarms to once every two or three months. Within a week I determined the cause of all of their piping failures, and performed subsequent calculations to stop pipeline breaks for a safety class fire protection systems in that nuclear weapons plant. The Pantex research led backgrounded a series of papers to stop water main breaks in the U.S. and throughout industrialized countries, where U.S. water main breaks presently cost 13 billion dollars per year. Engineers , world-wide, failed to understand water main failures for more than a century, prior to my research, and water main breaks can now be stopped.

In parallel to water hammer research, I invented the Leishear Explosion Theory to explain gas pipeline explosions and nuclear power plant explosions, which brings us up to date. When I saw the Fukushima explosions on television, I turned to my wife and said, "They just started the pumps." My theory was already published, and operators did not know that they needed to vent the hydrogen from the reactor to prevent an explosion. Seventy years of small nuclear power plant explosions have been identified, where the facts are that trapped gases reduce water hammer pressure surges. However, an explosions cause pressures to damage pipes and equipment. The research proposed here will prevent similar explosions from ever happening again.

The cause for gas pipeline explosions has been obvious to me for many years, but I have recently had time to publish those opinions as well, and four papers are in process for publication next year. For decades, corrosion has been considered to be the explosion cause – not true. If this fact were true similar explosions would occur in the steam industry and every other pressurized gas industry, but explosions only occur in the gas industry. There is no doubt that fluid transients cause gas pipeline explosions, and these explosions can be stopped. Engineers throughout the gas industry have failed to solve this problem for many decades, and the solution to stop explosions is now here due to my research, but some additional research is needed to convince others.

Here we are. Does a project succeed due to good budget and schedule preparations, or does it succeed because there is an extremely well-educated, hard-working engineer running the project? Both are required, where only good project management skills with inadequate engineering skills is a path to failure. For this research, years of budget and schedule compliance adds to a unique and extensive set of skills. I have dedicated my life to becoming a better engineer, and I have dedicated the past few years in preparation for this proposed modeling research. Two of my most recent in-process publications are the foundation for the project success of this proposal, and these papers are provided in Appendices B and C since they are not yet available to the public ("Nuclear Reactors are Not So Safe, A Question of Ethics", by Leishear, ASME, Journal of Nuclear Engineering and Radiation Science, and "The Fluid Transient Disaster", by Leishear, ASME, 2020, Pressure Vessel and Piping Conference.) Success is a natural outcome of diligence and hard work. Together, DOE and I can stop unnecessary deaths.

LELLC EXPERIENCE AND PERFORMANCE

Completing decades of engineering experience and project management, Dr. Leishear's extensive credentials follow. Basically, most of his life leads into this research to ensure project success through intense personal dedication. His experience and project performance follow. As part of full-time voluntary research over the past several years, Dr. Leishear has dedicated more than 20,000 volunteer hours and more than $130,000 of personal expenses over the past twenty years to stop piping failures and explosions.

Leishear Engineering, LLC, (LELLC), Experience

At LELLC and Savannah River Site, Dr. Leishear served in numerous positions, and the more pertinent positions are listed as follows.

- Expert in explosions in nuclear power plants, where numerous fire and explosion papers have been written (LELLC).
- Research Engineer at the Savannah River National Laboratory (SRNL), Pilot Scale, Fluids and Heat Transfer, Testing Laboratory.
- Quality Assurance Engineer for interpretations of NQA-1 and uncertainty analysis calculations for the SRNL Calibrations Laboratory (Metrology Engineer (Calibrations Engineer) certification earned from the National Voluntary Accreditation Program to perform instrument calibrations).
- Shift Technical Engineer responsible for implementation of the Safety Basis during nuclear waste Tank Farm operations at SRS. Oral boards were passed to earn a DOE Qualification Card certification as a Shift Technical Engineer.
- SRR Division Pump Engineer - Pump testing and pump applications engineer - responsible for numerous pumps that ranged from a few horsepower to hundreds of horsepower
- Piping engineer for nuclear fuel reprocessing facility (DOE Qualification Card requirements completed).
- SRS Site Expert for ASME B31.3 Piping Design.
- SRS Site Expert for Pump Design.
- SRR Vibration expert for compressors, pumps, and fans.
- SRNL Vacuum and high pressure systems expert and systems operator.
- International fluid flow, piping failure, and water hammer expert.
- Wrote a 2013 textbook for ASME Press, titled "Fluid Mechanics, Water Hammer, Dynamic Stresses, and Piping Design".

Leishear Engineering, LLC, Project Performance

Some of Dr. Leishear's past projects include:

- LELLC Research engineer investigating explosions in nuclear power plants. Published the Leishear Explosion Theory in the ASME Journal of Nuclear Engineering and Radiation Science.
- Dr. Leishear invented a new theory to explain and correct water main breaks, which damage 250,000 water mains per year in the US and Canada at a cost of 13 billion dollars per year. Published a new water main break theory in the ASME Journal of Pressure Vessel Technology.
- Published a new theory to document the next imminent nuclear reactor accident in the ASME Journal of Nuclear Engineering and Radiation Science.
- Published a new theory to prove that grit blasting of piping surfaces to prepare for surface coating actually damages the pipes to cause premature failures during fatigue.
- Performed research, as the Lead PI, for a 10 foot diameter tank to model mixing in an 85 foot diameter, one million gallon, nuclear waste storage tank. Dr. Leishear performed the experimental research and directed the Fluent finite element modeling research. In fact, Dr. Leishear repeatedly redirected modeling efforts to ensure success for this 1.5 million dollar project, where his practical expertise with fluids enabled him to see the problems with Fluent models before problems were encountered by modeling staff. This first-of-a-kind research determined SRS

operations parameters to effectively mix nuclear waste for further processing, where a requirement was met to not disturb radioactive sludge on the tank bottom. This research served for years as a guide to SRS mixing projects, and the results were published in the ASME Mechanical Engineering Magazine.

- Sole SRS Lead Engineer to determine the cause of numerous pump failures, which occurred in 60 days on 1.5 million dollar pumps. A 25 million dollar cost savings was documented in a Six Sigma Project, which accompanied ASME publications. This project was acknowledged as a Facility Evaluation Board Good Practice (FEB). Decades of pump failures preceded Dr. Leishear's research, and he extended pump lives to acceptable lifespans for the plant - albeit still not a long life for the pumps. He then served as the SRS engineer responsible for design and procurement specifications for three of these 1.5 million dollar, 150 horsepower pumps ($4,500,000 project), and he worked with purchasing to negotiate the contract, and inspected the pump manufacturer's plant to assess their capabilities. New theory on fatigue failures of mechanical seals for pumps was published at several engineering conferences, and that theory is now accepted as common knowledge in the pump industry.
- Principal Investigator (PI) for a 1.5 million dollar radioactive liquid waste mixing project, which was conducted at SRNL to effectively mix radioactive liquid waste in million gallon tanks at Hanford. A crucial safety requirement was to prevent explosive conditions that could be caused by mixing. Dr. Leishear experimentally proved that the two phase performance of radioactive sludge was far different than expected when air spargers were used for mixing the sludge, which is thick substance comprised of metals and oxides that are formed during nuclear fuel reprocessing. Experimental test results were published at a DOE Waste Management Symposium.
- Lead Engineer to solve 40 years of piping failures, where more than 200 pipes broke. Invented and published a new theory, called the Leishear Stress Theory, to explain this failure mechanism, where this work earned a 15 million dollar cost savings and recognition as an FEB Good Practice. Forty years of incorrect SRS reports claimed that corrosion was the problem, but when Dr. Leishear controlled water hammer, piping breaks stopped. To accomplish this project, Dr. Leishear performed hundreds of finite element models to model shock waves in a liquid as they travel along the bore of a pipe and expand the pipe wall to break the pipe in a fatigue process. The resultant Leishear Stress Theory was the crux of Dr. Leishear's engineering textbooks.
- Lead Technical Engineer to build a robotic arm to drill holes and take samples of steel in highly radioactive environments. Invented and published a new vibration resonance theory to explain why previous designs failed. That is, this new theory was used to achieve successful sampling. This project cost approximately 3 million dollars, where a similar project at another DOE plant, West Valley, cost in excess of 40 million dollars. The far more complicated West Valley design did not actually work, since vibration resonance caused the robotic arm to bounce off of the wall that was being sampled at West Valley. Dr. Leishear's work showed that West Valley reports were incorrect, and he corrected the resonance problem to actually drill and collect samples into the wall of a radioactive liquid waste storage tank. Dr. Leishear published the results of his new vibration resonance theory at ASME Conferences and DOE Conferences.
- Redesigned H-Tank Farm compressor system controls that operated improperly for several years. The compressor design was inadequate, and compressors were routinely out of service at a cost of one million dollars per year. Fatigue failures were corrected through system controls and associated equipment. Costs were drastically reduced, and similar compressor purchases were also corrected at the H-Canyon.
- Redesigned pump mounting to stop pump failures, which required around the clock maintenance repairs for decades. The vibrations were controlled and repairs were not required for the remaining five years of life for that system. Numerous engineers failed to solve the vibration problem for more than 60 years.

- Solved a two phase jet flow problem at the SRS H-Canyon facility, which could not be solved for the prior sixty years. A careful study of two-phase flow physics was performed, and the jet was properly resized to make it operate correctly. Results were published at an ASME Nuclear Engineering Conference.
- Solved a two phase pipe flow problem at the SRS H-Canyon facility, and this problem was unresolved for the prior forty years. A complex sequence of events caused a siphon of water to periodically spurt water into the air and also cause corrosion. A careful study of the problem proved that compressor repairs inadvertently dumped water four stories into a partially filled pipe - The water then splashed up into another pipe to cause corrosion - The corrosion caused a leak – Water burrowed an underground path to an open electrical conduit - Water then ran down through the conduit into an electrical motor control room – and a significant safety problem occurred when water from an unknown source entered an electrical room. The problem was corrected, but was not published.
- Registered Professional Engineer in the state of South Carolina.
- Appointed as an ASME Fellow by the American Society of Mechanical Engineers for "Outstanding Engineering Accomplishments".
- Earned the Mensa Copper Black Award for Intellectual Creativity for research on nuclear power plant explosions, and off-shore oil rig explosions, i.e., Three Mile Island, Fukushima, Chernobyl, and the Gulf Oil Spill.
- Earned a dozen SRS awards for various project accomplishments, which included cost savings, new theory, and a patent.
- Earned four ASME Awards of Service for volunteer contributions to ASME Codes and Conferences.

The Effects of Experience on Project Budget and Schedule

Working at Savannah River Site for 24 years with numerous technical successes, provided the skills needed to execute this project. Dr. Leishear published peer reviewed papers from most of his research to document success, and he served as a Project Engineer, Design Engineer, and Quality Assurance Engineer, which earned the mandatory skills needed to effectively manage this project. Decades of successfully managing numerous budgets and numerous schedules in a DOE operated facility ingrained the necessary Conduct of Operations and safety culture to clearly understand the relationship between project management skills and project success. For decades, Dr. Leishear has lived by the simple conviction that success is better than failure. Following this conviction carved a path of success behind him for others to follow. This research will carve another path for others to follow, where the technical merit of this work is supplemented by project management skills.

LELLC EDUCATION AND SKILLS

Dr. Leishear has earned an extraordinary education for the sole purpose of accomplishing this research, and he has years of additional training and experience that directly support this research project. Years ago, 2-1/2 years of engineering training were completed at SRS to understand aspects of nuclear facilities, instrumentation, and infrastructure. Many recent courses were selected to specifically support this research, and served to reinforce research conclusions as studies progressed. This education acts as the sharp pencil to spearhead this research project to success, where several years of full-time volunteer study and research have been completed to ensure the success of the modeling research proposed here. That is, myriad courses that Dr. Leishear attended prove a single conclusion: explosions can be stopped in U.S. and international nuclear reactor power plants!

Practical Experience

Working ten years in the construction trades, Dr. Leishear learned the skills to build nearly anything. He started out in welding and steel fabrication school. He followed up by working as a welder and shipbuilder on the last supertanker built in America, where he worked with cranes to place large sections of the ship (hundreds of feet wide by a hundred feet tall) in place to weld them together sufficiently to permit a crew of welders to complete the welds. He then moved on to earn his indenture papers to become a Journeyman Sheet Metal Worker, which required attendance at apprenticeship training classes two nights a week for four years. Trade school taught him to design, fabricate and bend flat metal into multiple forms. He installed sheet metal structures and duct work in high rise buildings and industrial plants. Due to the transitory nature of construction projects he filled in his work schedule as a carpenter, where he built homes and apartment buildings and supervised construction crews. While working in the trades, he earned a night school Bachelor's degree in Mechanical Engineering from Johns Hopkins University. This hands-on experience adds to a unique skill set to ensure project success.

Conferences and Committee Meeting Training

Dr. Leishear has received additional training while serving as a voting member of several ASME technical committees and attending more than 40 engineering conferences. As one of the committee members who forge national consensus piping and pressure vessel codes, he works to improve the ASME B31 piping codes, the B31.3 Process Piping Code, the ASME Section VIII Boiler and Pressure Vessel design code, explosively loaded pressure vessels, and high pressure piping and pressure vessels. Committee membership in itself is an informal education through interactions with piping and pressure vessel experts from around the country. In addition to attending technical short courses, conference attendance affords the opportunity to attend approximately 30 hours a week of technical presentations from around the world on pertinent engineering topics. Dr. Leishear also attended short courses that included the following.

- Nuclear reactor thermal hydraulics;
- Heat exchanger design;
- Turbine design;
- Seismic piping design;
- High temperature piping design:
- High pressure piping design;
- B31.1 Power Piping Design;
- B31.3 Process Piping Design;
- Nondestructive analysis;
- ASME Section VIII pressure vessel design;
- ASME Section II pressure vessel design;
- National Board Inspection Code;
- Piping flexibility analysis;
- Piping fitness for service;
- Piping failure analysis;
- Water main system design and failures;
- Water Works Public Official's Certificate.

Nearly all of this training supports the design, fabrication, and testing of equipment required for explosion evaluations.

Savannah River Site Training

Dr. Leishear completed two and a half years of full time engineering training at SRS (over 100 courses), in addition to all of the classes required to work as a qualified electrician and heating, ventilation, and air conditioning (HVAC) mechanic. Engineering and technician classes included the following.

- Control room operations.
- Air, steam, nitrogen, structural design; electrical, storm water, sewage, drinking water, and process well water distribution systems and associated equipment,
- Control room operations and instrumentation; Control Room Simulator training;

- Conduct of Operations; Conduct of Engineering; SRSOC (Savannah River Site Operations Center for emergency response) training and service during emergency drills;
- Instrumentation design and applications – Thermocouples, Pressure gauges and transmitters, Flow gauges and transmitters, Valve controllers, etc.;
- Nuclear engineering;
- Nuclear waste processes;
- Nuclear fuel reprocessing processes;
- Mixing processes;
- Nuclear material transportation and Safety Analysis;
- Electric motor design;
- Mechanical design;
- Compressor design and operations;
- Pump design and operations;
- Pump mechanical seal design;
- Rotordynamics;
- Diesel generator design and operations;
- Pressure vessel inspection and design;
- Non-destructive testing;
- Relief valve, Safety valve, Control valve design, Pressure regulator design;
- Safety analysis, Safety basis, Emergency response, First aid, Chemical and asphyxiation hazards;
- DOE regulations; OSHA regulations; NQA-1; ASTM, ANSI, and NIST codes; Hydraulic Institute pump design codes;
- Environmental regulations; Health regulations;
- Procedure writing;
- Radiation worker training; Radiology; Radiography; Radiation dose effects; Radiation monitoring equipment;
- Fire control systems; Fire protection;
- Heat transfer,
- Thermodynamics,
- Fluid mechanics,
- Chemistry,
- Radiation chemistry,
- Physics,
- Boiling processes,
- Vacuum systems,
- Materials science,
- Corrosion,
- Calibration (Metrologist) training and methods: Pressure, Vacuum, Mass, Temperature, Flow, and Electronics instrumentation and calibrations,
- Electrician training: Digital circuits; Analogue circuits; Distributed control systems; Variable frequency drives; Electrical wiring; Fuses, Heaters, and Breakers; the National Electrical Code; Electrical hazards and safety; Air conditioning electrical circuits, Air conditioning license, Refrigerants, Air conditioning repair.

While working at SRS, Dr. Leishear earned Master's and Ph.D. degrees from the University of South Carolina.

Project Management Training

Although Dr. Leishear has decades of successful project management experience, he recently attended classes for Project Management Professional (PMP) Training. This course provided a detailed study of the interrelationships between project scope, quality, schedule, communications, resources, risks, and stakeholders – all of which are essential to project success. PMP skills learned in this class were directly applied to the preparation of this proposal, and will be used during project performance.

The Effects Practical Education and Training on Project Budget and Schedule

Basically, Dr. Leishear has attended school at night for nearly his entire career, and this extraordinary background will minimize project schedule and budget upsets. He has a vast practical background on plant processes and equipment that provide insights into the day to day operations of nuclear facilities, although albeit these facilities were not reactor facilities. This practical experience provides a hands-on ability to understand plant problems and plant accidents that few engineers possess. This practical ability to understand complex plant accidents and facility operations further enables Dr. Leishear to avoid technical and operational pitfalls that might otherwise crash the schedule. Additionally, the sole purpose for attending the Project Management Professional course was to write this proposal and to ensure the success of this research project by better understanding project management principles which he has informally applied to projects for decades.

MECHANICAL ENGINEERING Ph.D.

Although Mechanical Engineering Bachelor's, Master's and Ph.D. degrees were completed years ago, those night school studies established the background needed to solve complex engineering problems throughout Dr. Leishear's career. Those studies are directly applicable to this research, and those degrees culminated in comprehensively understanding important aspects of failure analysis in piping and pump systems. The following formal university classes were attended.

Finite Element Analysis

Finite element analysis was studied to learn the complex technical basis of computer programs like Fluent, which will be used for this research. The following computer programs were used.

- Nastran,
- Abaqus.

Undergraduate Studies

Undergraduate night school studies at Johns Hopkins paved the way for graduate school. Technical studies included the following courses.

- Electrical Power Systems,
- Fluid Mechanics,
- Physics,
- Chemistry,
- Biology,
- Heat Transfer,
- Thermodynamics,
- Structural Design,
- Fortran computer Programming,
- Assembly Language Computer Programming,
- Computer Aided Graphics,
- Differential and Vector Calculus,
- Numerical Analysis,
- Advanced Mathematics,
- Engineering Economics,
- Statics, Dynamics,
- Machine Design.

Fluid Dynamics

Courses were attended to explain how fluids work in piping systems, as follows.

- Advanced fluid flow,

- Advanced mass transfer,
- Advanced thermodynamics,
- Acoustics,
- Heating ventilation and air conditioning design
- Water hammer,
- Gas dynamics.

This combination of courses synthesized an understanding of fluids, where two-phase flow;; supersonic gas flow; shock waves; fluid dynamics; and diffusion were inter-related. Essentially, these studies established Dr. Leishear as an expert in fluids dynamics and mixing of fluids, where all of his Mechanical Engineering graduate studies were directed toward troubleshooting of piping and pump system failures. All of this research is required to clearly understand the complex fluid-structure interactions that occur during piping explosions and building fires.

Structural Dynamics and Failure Analysis

To understand failure analysis and pipe system dynamics, the following courses were completed.

- Fatigue,
- Fracture mechanics,
- Materials science,
- Solid mechanics,
- Static system design,
- Structural vibrations,
- Machinery Dynamics,
- Stress wave mechanics.

Together, these classes explained how cracks start in pipes; how to determine the average time to failure for any given load condition; how to select materials for given environmental conditions; how to determine materials based on load conditions; how to determine the vibrations effects on piping systems, and how to understand the shock waves that travel through pipe walls and pipe supports to cause those vibrations. This collection of courses is required to understand why pipes crack or burst during pipeline explosions, depending on the magnitude of explosions.

Mathematical Analysis Background

Mathematics is thematic to engineering analysis, where courses were attended as listed below.

- Calculus,
- Differential equations,
- Vector analysis,
- Numerical analysis,
- Advanced mathematics, which included Linear algebra, Complex number analysis, and Fourier analysis.

In fact, mathematical techniques were the basis of inventing and publishing the Leishear Stress Theory that explains fluid-structure interactions and piping failures. An understanding of mathematics, allows one to take a step beyond the textbooks to solve engineering problems that were heretofore thought impossible to solve - a step beyond the edge of the impossible. As this project progresses a thorough mathematics background will lead to a better understanding of the explosion processes under consideration.

The Effects of Post Graduate Studies on Project Budget and Schedule

This plethora of advanced engineering studies was paid for by DOE budgets and was completed over many years, predominantly at night – Dr. Leishear attended night school for decades for different degrees and training. An outstanding understanding of piping system failures was earned during this research, and again a keen understanding of the physics of this proposed research limits the risks associated with new research schedules and budgets. His education is unlikely paralleled by anyone. As matter of fact, this extensive education was completed while working at Savannah River Site, and the University of South Carolina permitted Dr. Leishear to take whatever classes that he wanted to take. Accordingly, he studied classes at different universities and in different departments at USC to earn a degree uniquely tailored to a strong understanding of piping system failures and all of the scientific disciplines needed to understand them. Basically he studied fluid system operations and failure analysis. These skills will be essential to achieving project success and enforcing schedule and budget compliance.

NUCLEAR ENGINEERING, Ph.D.

To prepare for this part of the explosions research, Nuclear Engineering was studied to clearly understand the operations of a commercial nuclear power plant. Dr. Leishear needed a strong background in this field of study to ensure that his fire and explosion theory (the Leishear Explosion Theory) was correct. In other words, Dr. Leishear is earning this PhD for the sole purpose of stopping fires and explosions in nuclear power plants. Accordingly several areas of study were pursued as follows.

Nuclear Fuel Cycles

The nuclear fuel cycle was studied to understand the overall processes required to create energy from nuclear fuel. Pertinent topics included:

- Mining, milling, and processing of uranium to be used as nuclear fuel.
- Fabrication of reactor fuel rods and fuel assemblies for insertion into the reactor core.
- Reactor design principles and economics.
- Storage and disposal of reactor fuel rods.

Nuclear Reactor Designs

Reactor Design classes were essential to understand the differences between different nuclear reactor designs, which affects not only the basic operations of those reactors, but affects the manner in which hydrogen may explode during meltdown accidents. However, all of these designs generate hydrogen during operations that can cause piping explosions. Nuclear Reactor Design considered:

- Support systems for nuclear power plants.
- Nuclear physics, reactor physics, reactor control, radiation, and fuel depletion.
- Self-study textbooks in the areas of reactor cores, radiochemistry and the radiation chemistry of water were also studied.

Radiation Shielding

Radiation Shielding considered the various types of radiation that are generated in nuclear reactions. Radiation considerations are different in the reactor core, where neutrons striking water release energy. In the event of a radioactive release to the public other forms of radiation, like gamma rays, may be more important, where gamma rays destroy human cells to cause cell damage.

Nuclear Reactor Safety Analysis and Risk Assessment

Safety Analysis and Risk Assessment investigated different numerical techniques used to explain the statistical variation in the likelihood of nuclear reactor accident. Probabilsitic Risk Assessment (PRA) predicted that a failure similar to Three Mile Island was the most dangerous accident concern for reactor operations, but this finding was not acted on until TMI occurred. NRC regulations now require PRA to ensure safe operations for operating reactors and new reactors. However, this research proves that current NRC regulations cannot be correct if one accepts the principals of PRA and the conclusion that fluid transients cause explosions, as presented herein.

Nuclear Safeguards and Security

Nuclear Nonproliferation and nuclear power plant radioactive material control is applicable to NRC regulations and nuclear law, but has little specific application to this research.

Nuclear Reactor Thermal Hydraulics

Thermal Hydraulics investigated the complex relationships between cooling water and the radioactive core, which included:

- Thermal design principals.
- Reactor energy distribution, i.e. reactor radiation flux distribution and absorption by water to convert radiation to thermal energy.
- Heat transfer from within the fuel rods to the water of the core.
- Boiling processes in the core for different reactor designs.
- Fluid flow processes in the core.

This class was essential to understand the complex relationships between fluid mechanics and radiation, where these processes may ultimately cause explosions and fires.

Nuclear Materials and Metallurgy

Nuclear Materials investigated different materials used in reactor design and the various failure mechanisms that affect those materials. Both microscopic and macroscopic material failures were investigated. This course was essential to understand core meltdowns and hydrogen generation from fuel rod deterioration at high steam temperatures.

Advanced Nuclear Reactor Core Design

Advanced Nuclear Reactor Core Design investigated all of the closed form mathematical solutions which describe simple geometries that can sustain a continuous nuclear reaction. That is, complex reactor designs perform exactly this purpose to yield a continuous source of electricity, where thermal energy is converted to electrical energy. The core ultimately provides steam to rotate an electrical generator for electrical power supply. Closed form solutions have limited applicability, where computer aided design is required for a thorough analysis of thermal hydraulics.

All in all, these courses provide requisite skills to perform computer aided design. Processes must be clearly understood when undertaking the more complex computer models.

Post Graduate Combustion Courses

In addition to Nuclear Engineering studies at USC, combustion Institute classes were attended at Princeton University for the following topics.

- Combustion Physics,
- Combustion Kinetics and Chemistry,
- Solid Explosives,
- Combustor Theory,
- Experimental Combustion Video Techniques,
- Combustion Dynamics,
- Numerical Soot Combustion.
- Fundamentals of Numerical Turbulent Combustion, National Energy Agency (CERFACS) course.

To parallel these undergraduate and graduate combustion classes, the following textbooks were self-studied.

- “Combustion”, Glassman,
- “Combustion”, Turns,
- “Explosives Engineering”, Cooper,
- “Combustors”, Lieuwen,
- “Detonations”, Lee.

A clear understanding of combustion principles is essential to this research.

Post Graduate Corrosion Courses

Also in addition to Nuclear Engineering studies at USC, courses were attended through the National Association of Corrosion Engineers to understand corrosion in pipelines. This training is applicable to the current research since several kilograms of corrosion product accumulate in pressurized water reactor steam generators, during 18 month reactor shutdown maintenance intervals. Then, as resultant corrosion particles circulate through the system, they collect boron particles, which in turn collect on fuel rods, act as neutron poisons on the control rod surfaces, diminish the neutron flux, and decrease reactor power production. This decrease in power production affects hydrogen production due to radiolysis. Additionally, Dr. Leishear has significant practical experience resolving pump and piping corrosion problems.

Numerous NACE (National Association of Corrosion Engineers) corrosion courses were completed to support his research. These courses included the following.

- Internal Corrosion,
- Advanced Internal Corrosion,
- Protective Coatings Specialist,
- Cathodic Protection Tester,
- Cathodic Protection Technologist,
- Cathodic Protection Specialist,
- Corrosion Design.

NACE Certification as a Senior Internal Corrosion Technologist has also been earned. These courses are directly applicable to this research, since an inherent safety problem was discovered during this corrosion education with respect to nuclear reactor piping systems. Specifically, fatigue properties are drastically reduced by grit blasting during surface preparations for coating application. In fact, the number of cycles to failure can be reduced by as much as 98%, which will cause nuclear reactor piping to fail prematurely when subjected to periodic, small-scale explosions, which are proven to occur by this ongoing research. This new theory was published. Another aspect discovered during corrosion courses was the evaluation of gas pipelines, where these studies evolved into a new understanding of gas pipeline explosions, which are now known to be caused by fluid transients. This additional new theory has also been published.

The Effects of Post Graduate Nuclear Studies on Project Budget and Schedule

This Nuclear Engineering PhD degree is complete with the exception of performing the research specified in this proposal, and the sole purpose of studying many long hours was to prepare for this research to ensure that success is ensured. This effort brings schedule and budget together in a remarkable manner. The first three and a half years of this project were the first phase of this research, and the grant request presented here asks that DOE pay for the next two years of research. In other words, six thousand hours have been invested to ensure project success – on time, and within budget.

NUCLEAR REACTOR COMPUTER MODELING SOFTWARE COURSES

Parallel to post graduate studies, numerous reactor classes were attended to enable modeling of the nuclear reactor phenomena that precede fires and explosions in reactor systems. Some classes were used to determine a path forward for this research, and are not discussed here in detail, but applicable classes are briefly discussed below.

Software Courses Attended

Numerous software courses were attended to perform the proposed modeling required for this proposed research, and a discussion of their use follows. Attended courses include the following.

- Parcs, Reactor physics,
- Relap5, Nuclear reactor thermal hydraulics,
- Polaris, Nuclear cross sections,
- Keno, Nuclear cross sections,
- Mvrik, Nuclear shielding,
- Tsunami, Nuclear physics uncertainty calculations for reactors,
- Origen, Nuclear fuel depletion,
- Triton, Nuclear cross sections,
- Trace Nuclear reactor thermal hydraulics.

Nuclear Reactor Thermal Hydraulics Modeling

Thermal hydraulic programs are best estimate programs that implement closed form equations into calculations to significantly reduce computer simulation time. Both Trace and Relap5 are approved for use by NRC, but Relap5 is no longer updated by the NRC. This most recently approved version will be used for this research, since Relap5 has the capability to model supersonic flow, but Trace does not. Also the NRC has provided an input deck for Three Mile Island, Unit 1, which can be modified to simulate the TMI-2 model that experienced a meltdown and hydrogen fire. Classes for both Trace and Relap5 were attended.

Nuclear Reactor Core Modeling

Reactor Core modeling will be investigated, using Parcs, which performs simplified reactor flux calculations, while interactively coupled to Relap5. During previous classes, Dr. Leishear used available reactor input decks to simulate reactor loss of coolant accidents. These input decks will be combined with the NRC provided input deck to model normal operations and near-meltdown conditions, where hydrogen generation is maximized. Some additional data will be required for thermodynamic and flux data that is not available within the available input decks. This information will need to be generated using thermodynamic equations and Polaris reactor lattice physics models, where a lattice is used along with neutron transport equations to model an array of fuel rods in a core. If time permits, Keno models will be used to spot check Polaris results. Keno uses random Monte Carlo simulations to model the neutron flux in a reactor, where this more accurate calculation is different than the Parcs technique and provides a method to cross check results for accuracy. The Polaris results will then be entered into Parcs for reactor simulations near meltdown, where Relap5 has the ability to model partially blocked reactors. Both programs use ENDFB and other nuclear cross section data. Origen will be used to evaluate fuel depletion effect for comparison to the coupled Parcs / Relap5 models. Classes for Parcs, Keno, Origen, and Polaris were attended, since they are mandatory to complete this project.

To determine the modeling approach to this research, other reactor design classes were also attended. Courses included Tsunami for reactor flux uncertainty analysis, Mvrik for radiation shielding, and Triton for nuclear reactor core physics, where the more complicated Triton provides the technical basis for the Polaris light water reactor design code. However, Tsunami, Mvrik, and Triton will not be used during this research, where they were deemed to not be directly applicable to the research at hand. Tsunami is valuable, but in the absence of an uncertainty analysis program to consider thermal hydraulics, this code has little applicability to this research, even though the uncertainty of some flux calculations may be a s high as 10%. Triton duplicates Polaris results and Triton will not be used. Mvrik describes the full spectrum of radiation that can cause radiological damages to equipment and people. Mvrik considers the different types of radiation, i.e., gamma, beta, and neutron and their interaction with matter. However, radiological doses are not a focus of this research, where only the reactor neutron flux will be considered using Keno (time permitting) and Polaris.

Nuclear Reactor Hydrogen Generation Modeling

Frapcon (normal operation) and Fraptran (transient operations) have not been studied, and will need to be self-taught since there are no classes to attend. However, these programs model the hydrogen generation due to Zircalloy corrosion in the core. Calculations for hydrogen due to radiolysis and thermolysis will be performed to determine the hydrogen quantity needed for input into Fluent to investigate explosions. However, radiolytically generated hydrogen calculations may be used to demonstrate reactor explosion theory.

ADDITIONAL COMPUTER MODELING COURSES

Essentially, classes were taken all over the world to ensure a comprehensive understanding of computer modeling. Computer program courses were studied for the following topics for the sole purpose of stopping nuclear power plant fires and explosions. A list of completed courses follows.

Fluent CFD Fluids and Combustion Modeling

Fluent is a computational fluid dynamics (CFD) program, which uses finite element modeling to model complex fluid processes such as combustion, supersonic flow, and fluid dynamics. Completed courses included the following.

- Combustion,
- Heat Transfer,
- Fluent Fundamentals,
- Multi-phase Flow,
- Turbulence,
- Dynamic Meshing,
- User Defined Functions,
- APDL and MAPDL programming,
- Rotor Dynamics.

This assembly of programs can provide detailed information about the fluid and compression processes that cannot be discerned from the best estimate programs that are used to model nuclear power plant processes. Completed courses follow.

Ansys Structural and LS Dyna CFD Modeling

Ansys can be used to evaluate fatigue and maximum stresses due to explosions. Completed courses include: fundamentals, explicit dynamics, material nonlinearities, structural nonlinearities, linear and nonlinear dynamics, connections, fatigue, and LS Dyna. All of these classes provide a comprehensive set of tools to model material failures due to fatigue for gas accumulation events in reactors (Ansys) or to model rupture during piping explosions (LS Dyna). Additionally, fluid-structure interaction modeling can be used to explore piping explosions, where Ansys and Fluent perform coupled models that interact as a modeling event occurs with respect to time. Unfortunately, Fluent and LS Dyna are not coupled, and subroutines will be required to facilitate explosions modeling. Even so, Fluent programs are the crux of the fire and explosion modeling for this research.

AFT Water Hammer Modeling

AFT Impulse was studied to prepare for this research. Although Dr. Leishear has used other programs to model fluid transients, AFT Impulse has the advantage of NQA-1 qualification to ensure the validity of results. This program will be used to approximate gas accumulation events in piping systems in conjunction with Fluent models to provide a comprehensive understanding of the complex dynamics of explosions and fluid transients to stop equipment damages in reactors.

The Effects of Modeling Studies on Project Budget and Schedule

Computer modeling of reactor operations, fluids, structures, and explosions are the heart of this research. The better these models are understood, the higher the probability of successful budget and schedule management. To this end, courses have been attended in many cities and several countries. Dr. Leishear travelled wherever he needed to go, and paid whatever he needed to pay to ensure a high probability of project success.

INTERNATIONAL NUCLEAR LAW ESSENTIALS COURSE

INLE was attended to understand the relationships between international nuclear law and US nuclear regulations. With respect to this research, US NRC regulations were determined to be inadequate and unsafe with respect to hydrogen explosions. Textbooks on international law were self-studied in preparation for this class. Legal challenges to NRC regulations are expected to follow this research project and Ph.D. completion, where this course provided adequate legal background to pursue this objective. In fact, legal forms that are required to change NRC regulations were provided.

International Nuclear Engineering Law Studies

Textbooks on Introduction to Law and International Law were self-studied in preparation for this class. Also, undergraduate courses in Engineering Law, logic, philosophy, U.S. government, and state and local governments paved the way for this International Nuclear Engineering Law course in Singapore. This nuclear law course in Singapore discussed topics that included the following.

- Commercial nuclear reactor treaties,
- Nuclear facility licensing, regulation, construction, financing, safety, liability, insurance,
- Safeguards, security,
- Trafficking, terrorism, transportation,
- Accidents at Chernobyl, Three Mile Island, and Fukushima.

This suite of classes enables an understanding of the relationship between International Law and U.S. law with respect to NRC regulations that govern U.S. reactor fleet operations. In fact, this class provided the appropriate documentation needed to challenge an NRC regulation, where a primary goal of this research is to change NRC regulations to ensure safe reactor operations. Specifically, NRC regulations are incorrect with respect to accident frequencies for large scale radioactive releases.

The Effects of Nuclear Law on Project Budget and Schedule

Nuclear Law has little influence on budget and schedule. However, these studies provided a guide to understanding the relationship between nuclear law and operating facilities. In fact, ex-NRC personnel who taught the course provide guidance on how the change NRC regulations, which, of course, is a parallel goal of this research. In other words, prove the methods to stop explosions, and then pursue safety changes to the NRC regulations. Although commercialization is not a specific goal of LELLC, a change in regulations would certainly accelerate commercialization by the nuclear industry.

INTERNATIONAL RADIOLOGICAL PROTECTION SCHOOL

IRPS classes were attended to understand radiological protection requirements, regulations and the current state of the art in biological, epidemiological and social science fields as applicable to radiological protection. This course was attended to better understand the radiation effects on people in the wake of a nuclear accident. From information presented in this course, a determination was made that many of the documents used by government agencies to prove nuclear reactor safety are misleading. Those documents use statistics and probability claim that nuclear reactor accidents will occur once every 100,000 years. However, the fact is that nuclear accidents can be proved to occur every 27 years using statistics and probability, since there have been 10 nuclear power plant accidents since 1954. The difference between purely mathematical predictions and mathematical analysis of past accidents is remarkable – extremely unlikely on the one hand but imminent danger on the other hand. Accordingly, the next accident is expected in 2038.

The Effects of Radiological Protection Training on Project Budget and Schedule

This school has little direct bearing on budget and schedule, but was attended to better understand the aftermath of nuclear accidents when people are exposed to radioactive materials. As noted, an extremely important discovery was made while attending this class. A new finding now proves that commercial nuclear plant operating data has been has been unintentionally misrepresented for decades. As discussed below, nuclear reactor plants are far less safe than have been previously believed, and this finding is based on prior research.

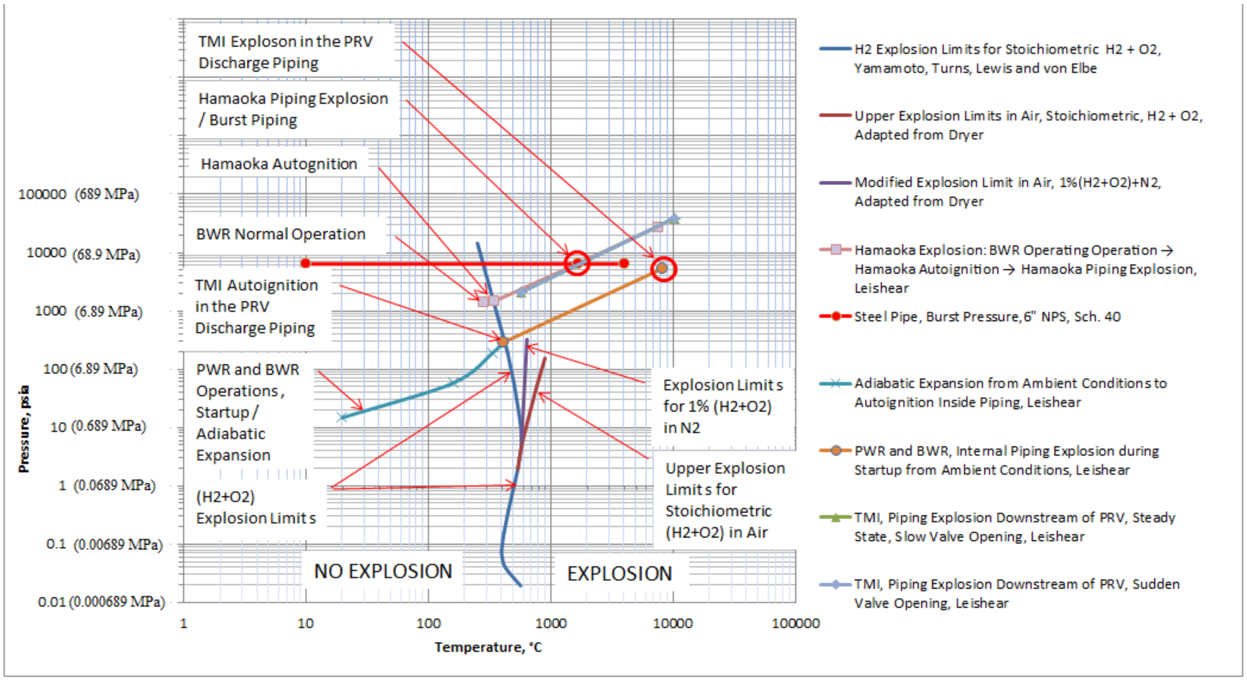


Figure 2: Autoignition Temperatures for Normal Reactor Operations and Accident Conditions
(Leishear [12])

PRIOR VOLUNTEER EXPLOSIONS RESEARCH TO DATE

Extensive research[1] was performed in preparation for computer modeling. This research resulted in numerous publications that can be summarized in the following Background summary. Does this summary belong in this Past Performance section of this report? Yes – this background documents the Past Performance for this specific project, and this background clearly defines the extreme importance of this research and Dr. Leishear's dedication to this research. Should this background information be included in the Narrative File? Perhaps, but the purpose of the Project Narrative File is to focus on what needs to be done rather than what has been done. All in all, this discussion lays the foundation to understand the scope of this work to stop nuclear power plant explosions, save lives, stop environmental damages, and stop nuclear plant damages.

Background of Nuclear Power Plant Explosion Research

Before planned research is considered below, a background of explosions research to date must be considered. After all, the Leishear Explosion Theory that explains these explosions has not yet been accepted by regulatory agencies and many engineers. This theory is comprehensively documented in a series of papers (Leishear [1-12]), and these papers conclusively prove that many, but not all, explosions in nuclear power plants are caused by fluid transients[2]. Even so, there is a single autoignition mechanism – reactor operations form hydrogen, fluid transients compress hydrogen - compression heats hydrogen, heated hydrogen ignites on contact with oxygen if the temperature is high enough - and the gases explode.

[1] References are listed in the Project Narrative for this FOA.

[2] Two Chernobyl explosions, separated by seconds, were caused by a criticality that caused the reactor power to momentarily spike by a factor of 100 or more. The initial explosion was primarily due to thermolysis, and the second explosion occurred when hydrogen from Zircalloy-steam reactions was blown from the exploding reactor into the air of the reactor building. Air plus hydrogen plus molted fuel equaled the second explosion (Leishear [13]). Although thermal-fluid transients occurred during these explosions, transients were not a contributing cause to explosions.

In short, hydrogen is generated by different mechanisms in reactors, and the compression process heats hydrogen to ignite in different scenarios at the autoignition temperature of hydrogen (Fig. 2)[3].

Figure 3: Hamaoka, Japan, Nuclear Power Plant, Piping Explosion, 6” Dia., Sch. 40 Pipe (Leishear [8])

Figure 4: Nuclear Power Plant Pump Restarts Autoignite Explosions (Fukushima shown)

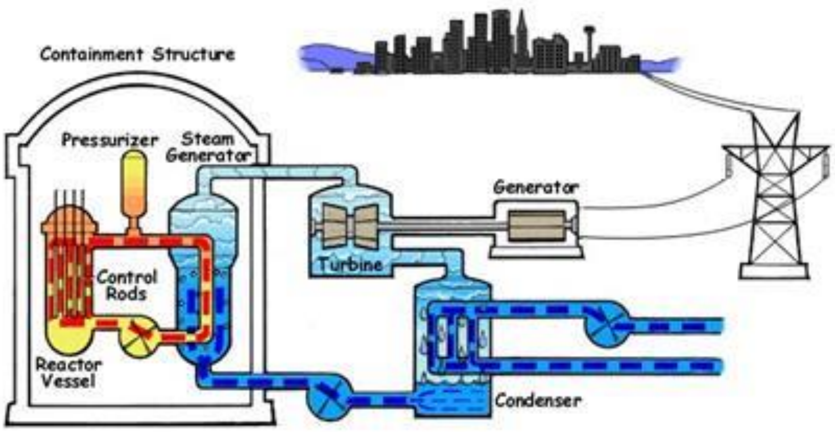


Figure 5: PWR Configuration (NRC)

[3] Previous reports by the NRC, Chubu Electric in Japan, OECD NEA, the IAEA, and the Japan Atomic Energy Research Institute concluded that the ignition cause of nuclear reactor explosions is unknown and cannot be determined. These reports observations are untrue, but those reports were used as a technical basis to support this research.

Figure 6: BWR Fuel Rod Assembly and Fuel Pellets (NRC)

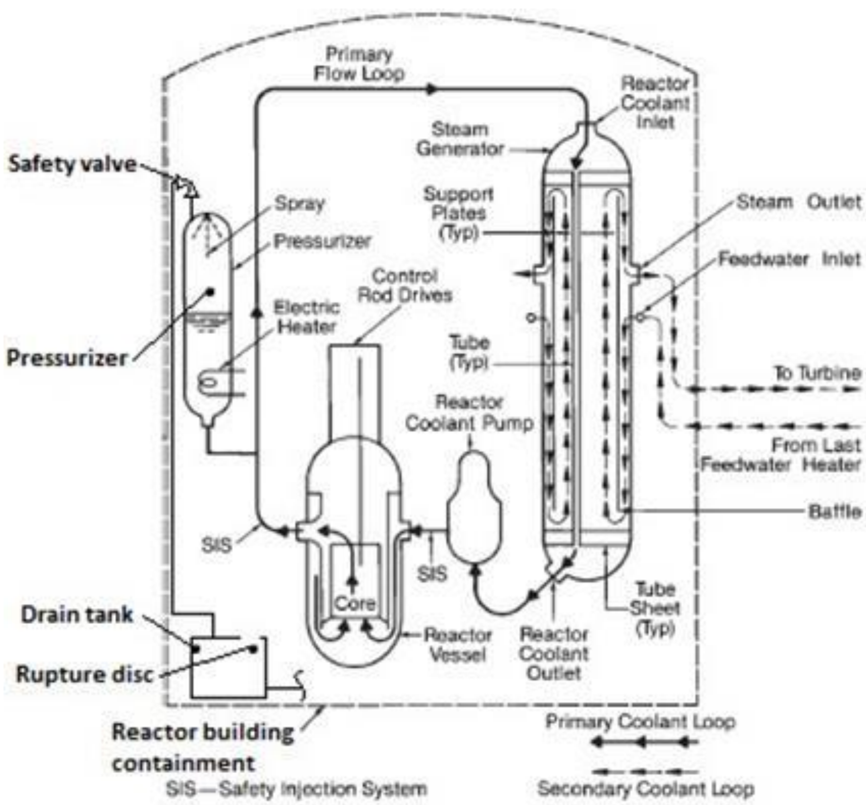


Figure 7: TMI RCW Schematic (NRC)

The Size of Explosions

The size of the explosion depends on how much hydrogen is present in the reactor system at the time of the transient. Explosions can be negligible (equivalent to a fire cracker), or explosions can be significant like those at Fukushima, where explosions were estimated to equal the equivalent of 800 kgs of TNT (Kuzentsov, et al [13]). Small hydrogen explosions may result in fatigue cracks in piping, larger amounts of hydrogen explode pipes (Fig. 3), and even larger amounts of hydrogen cause explosions that blow buildings apart (Fig. 4). Again, the explosion cause is the same - only the size of the explosion and the resultant damages change. As shown in Fig. 2, there are numerous scenarios that cause explosions in boiling water reactors (BWRs) and pressurized water reactors (PWR's), and these scenarios depend on the operating conditions.

Explosions During Normal Operations

During normal operations, hydrogen and oxygen are formed when radiolysis dissociates water with radiation, and these flammable gases collect at system high points to be exploded when a transient occurs at a later time. This scenario resulted in the Hamaoka explosion, and calculations proved that a fluid transient caused this explosion (Leishear [8]). Also, gas accumulation events have been reported since the 1950s when reactors were first operated, and prior to this body of research water hammers were believed to be the cause of these events. However, water hammer alone actually decreases the pressures caused by transients, and the common causes are explosions caused by fluid transients, or water hammers. In other words, small explosions, perhaps hundreds of explosions, have been occurring for nearly 70 years in reactor systems throughout the U.S. reactor fleet and world-wide.

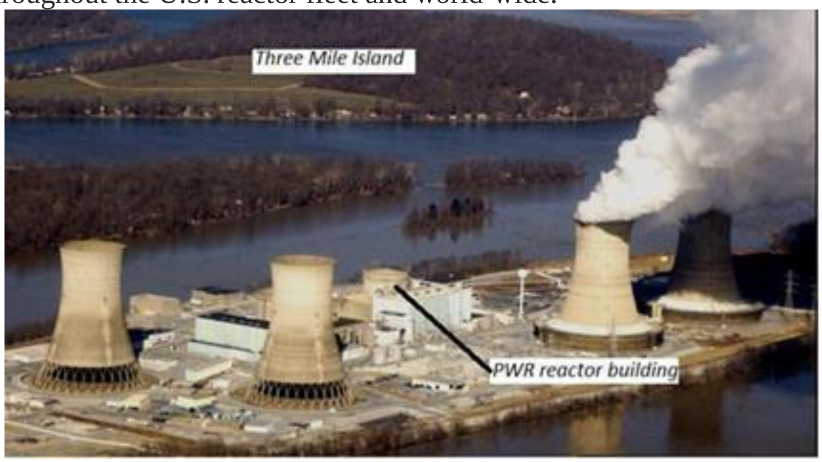


Figure 8: TMI Nuclear Reactor Plant (NRC)

Meltdowns and Explosions

During the complex meltdown processes, several explosions occur. To explain this statement, consider Figs. 5 and 6, where Fig. 5 describes the accident at Three Mile Island, Unit 2 (TMI-2), and Fig. 6 shows a typical tube bundle and fuel pellet for a BWR like those at Fukushima. As the water level in the reactor core lowers due to an accident condition the core becomes uncovered, and as the level continues to drop the reactor fuel rods heat. At first, the cladding that surrounds the fuel pellets to hold then in place approaches the cladding melting temperature, and steam in contact with this Zircalloy cladding yields large volumes of hydrogen. In this initial phase of meltdowns, hydrogen cools as it expands up into the reactor piping.

For TMI-2 and Fukushima, this this large volume of hydrogen was released from the piping without ignition to mix with air in the reactor containment building – an explosion is waiting to happen. During the next step in the meltdown, fuel temperatures continue to increase and the uranium fuel melts with molten Zirconium and molten steel from fuel rod components to form a substance called Corium. To cool the core, water is added and any sudden addition of water to the core will induce a process known as thermolysis, which dissociates water into hydrogen and oxygen. Since molten fuel is present this combustible gas mixture may explode, depending on the quantity of flammable gas and steam. This explosion mechanism is outside the scope of this research, but some insight into thermolytic explosions may be incidental to this research.

As the reactor coolant water (RCW) system continues to be refilled with water, flammable hydrogen is heated by compression. When this high temperature hydrogen was released to the reactor containment building, the heated gas acted as a spark source and ignited the hydrogen and air in the containment buildings, and large explosions occurred. For TMI-2 and Fukushima, the cause of the meltdown and the path of the hydrogen to the containment building differed, but the basic explosion scenario was the same.

For explosions at both sites, water was added at the same time that explosions occurred. For example, log books for one Fukushima explosion showed that a pump was started, and minutes later a building explosion occurred. Other Fukushima explosions also occurred while water was added to cool the reactor cores. Similarly, explosions at TMI-2 were caused by fluid transients.

Figure 9: TMI RCW System and Reactor Core (NRC)

TMI-2, Proof of Explosion[4]

To present a reasonable proof of this theory, consider the TMI-2 explosion. A fluid transient explosion theory was unavailable at that time, and a 319 kg hydrogen fire was believed to have occurred. This ongoing research into multiple reactor accidents proved that an explosion occurred. A careful study of Chernobyl, TMI-2, and Fukushima concluded that t a fire at TMI-2 did not fit the facts, and a closer study of TMI-2 was performed. The work of Henrie and Postma [14] and NRC reports provided information for this investigation, and a description of TMI-2 is provided in Figs. 7-9.

Several facts prove that explosions occurred at TMI-2, where an understanding of the chain of events for explosions has evolved during years of research (Leishear [4,5,6,9,13]). In fact, this author believed published government reports, which stated that a fire occurred, until the following facts proved otherwise.

1. The presence of a thermolytic explosion is probable at the first moment of water additions, but has not been proven.

[4] Calculations are also available in referenced papers, which document the Hamaoka fluid transient explosion and the Chernobyl criticality accident explosions.

2. The first fluid transient explosion occurred when water was blown out of the drain tank through a blown rupture disc.
3. The drain tank is piped to the reactor system safety valve, which relieved pressure from the RCW system during this accident.
4. The drain tank level indicator did not have a recorder, but was observed to indicate that the drain tank was empty. Since a fire was assumed to have occurred, this instrument was arbitrarily assumed to be incorrect.
5. This first explosion only ignited hydrogen and air inside the piping between the safety valve and the drain tank, and the flame was extinguished by the time that the water blasted from the drain tank into the containment building. No pressure measurements were recorded for this first explosion.
6. The second fluid transient explosion occurred at the same time that a safety valve opened to the reactor containment building. Hydrogen inside the RCW system was heated to high temperatures, and when this heated hydrogen blasted from the safety valve it ignited the hydrogen and air in the reactor building.
7. At this time there was an open path from the safety valve to the containment building. Temperatures measurements indicated that the piping near the safety valve increased in temperature.
8. Within seconds of the explosion, a pressure spike was recorded that went off the chart on the pressure recorder.
9. This explosion pressure measurement was ignored, and a lower pressure has been subsequently reported since 1979.
10. This lower pressure followed the measured explosion pressure.
11. In other words, the explosion at TMI-2 was falsely believed to be a fire for forty years.
12. The following calculations support this conclusion.

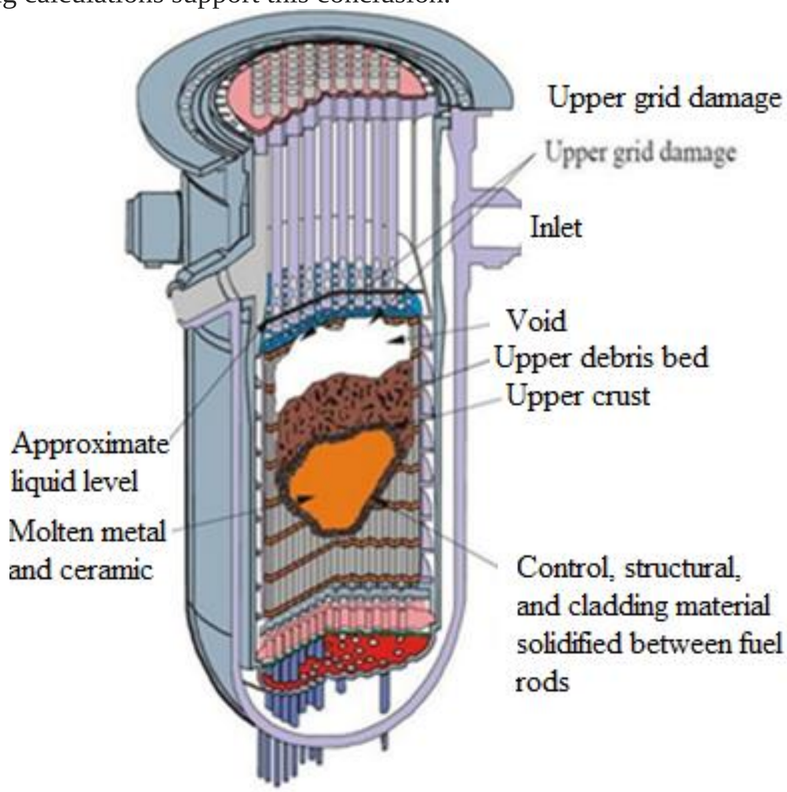


Figure 10: TMI Reactor Core Damage (Adapted from nrc.gov)

TMI Hydrogen Explosion Calculations

These calculations are copied from Leishear, R. A., 2019, "The Autoignition of Nuclear Power Plant Explosions", Journal of Radiation Science and Technology, American Society of Mechanical Engineers and 44 references are provided in that paper.

The 1979 TMI, PWR accident resulted in a reactor core meltdown, which melted half of the reactor core fuel rods, as shown in Fig. 10. The meltdown was caused by operator errors and equipment failures. The focus of this study concerns the hydrogen explosion, where much literature is available to describe the sequence of events leading to the explosion.

Within 8 seconds of a reactor trip, non-explosive thermal-fluid transients opened both the PRV and the safety valve at pressures of 2435 psig. Thousands of gallons of RCW were inadvertently dumped from the reactor (See Fig. 7) through the ruptured disc of the pressurized relief tank. The plant shift manager stated that the cavitating reactor coolant pumps sounded like "the gates of hell had opened up" as the reactor system lost coolant water.

During the meltdown, 460 kilograms of hydrogen were released through the pressure relief valve (PRV) into the RB, and 319 kilograms exploded. Calculations show that cladding failed and hydrogen generation stopped near the time of the first explosion, which implies that approximately half of the hydrogen was generated by thermolysis, where only ¼ of the Zircalloy had corroded, where 225 kg of the 319 kg of total hydrogen were formed. Note that, thermolysis and Zircalloy corrosion were not modeled within the Corium, using MELCOR. This finding significantly advances the understanding of hydrogen generation during reactor accidents, where an oxygen source was present to cause an explosion inside the reactor pressure vessel at the time of the building explosions.

While the meltdown occurred, the system was refilling with cooling water, which compressed residual hydrogen in the RCW piping. This heated, or detonated, hydrogen was released through the PRV to ignite the hydrogen and air in the reactor containment building.

This research concluded that refilling the system compressed the hydrogen in the piping to heat it to high temperatures. When hot hydrogen gas was then exhausted, or vented, to the containment building through a PRV, the hydrogen gas autoignited on contact with air.

To further prove this explosion theory, research showed that:

1. The PRV opened 6 seconds after the reactor tripped, i.e., prior to the presence of hydrogen in the building.
2. The rupture disc burst less than 15 minutes after the initial reactor trip, as indicated by a 04:11 sump high level alarm and 04:20 radiation alarm. Rupture discs are selected to catastrophically fail if the piping pressure exceeds the safety limit, or design margin.
3. The PRV opening time was coincident to the time that an explosion from the reactor RCW system ignited the explosion. Although a 30 second to one minute time delay between valve opening and temperature recordings has been noted in reports, thermocouple temperature data was only recorded every 6 minutes, even though thermocouple response times were less than 5 seconds. Conclusively, the PRV opening and ignition of the building explosion is consistent with accident data.
4. The pressurized relief tank was emptied through a burst rupture disc, where a level indicator behind a control room panel indicated that the tank was empty. Previous reports concluded that this gauge must have malfunctioned, since a mechanism to empty the tank was not identified. This research shows that explosions emptied the tank – the gauge was correct.
5. Consequently, there was an open path from the PRV to the containment building, where the PRV connected to a pressurized relief tank through 36 inch NPS piping (Fig. 7).
6. The pipe temperature upstream of the PRV increased immediately prior to the explosion, and the downstream piping temperature increased when the PRV opened.
7. The oxidation of Zircalloy with steam was the principal source of the hydrogen that burned at TMI. According to an International Atomic Energy Agency document, the Zircalloy reaction created 85 to 90 percent of the hydrogen during this meltdown. However, this research shows that thermolysis may generate as much as half of the hydrogen during the TMI accident.
8. Postulated by the International Atomic Energy Agency, the remaining 10 to 15 percent of hydrogen

was likely caused by oxidation of steel in the core, but this research shows that thermolysis was also a hydrogen contributor to accidents.

9. Radiolysis was considered by IAEA to be a minor initiator of hydrogen immediately after the TMI accident. Note that radiolysis and thermolysis are initiators for free oxygen to support combustion inside the reactor.
10. During normal PWR operations, excess hydrogen is used to scavenge hydrogen from solution, but oxygen will diffuse along with hydrogen to high points of the piping system. This observation is supported by the fact that hydrogen and oxygen accumulated in Hamaoka high point piping, where hydrogen was used as a scavenger in a BWR.

TMI explosion calculation details

A careful study was performed to understand the TMI combustion processes. The results of this study follow.

Operating and transient conditions. First, the gas temperature at the high point PRV increased due to pump refilling of the RCW system, where the maximum temperature increase was sufficient to raise the hydrogen temperature above the autoignition temperature. This temperature increase describes the upstream conditions at the PRV at the time that the valve opened (Eq. 11). To understand the temperatures at the PRV, the RCW system conditions need to be better understood.

At the time of the reactor trip, the RCW system was operating near 575°F and 16.8 MPa (2435 psig). The TMI PRV set point was 15.55 MPa (2255 psig), and the set point for the safety valve was 16.1 MPa (2335 psig), where safety valves are typically set at 15% above maximum pressure and temperature design conditions per ASME Boiler and Pressure Vessel Code requirements. There were several transients during recovery, but the average temperature and pressure from 06:00 to 14:00 were 575°F and 14.48 MPa (2100 psig), where these conditions exceed the autoigntion curve for hydrogen (See Fig. 2).

Assuming that these conditions are the same throughout the pressurizer and attached piping up to the PRV, any constant temperature hydrogen, that was generated from thermolysis or radiolysis, would have remained mixed with steam. Again, most of the hydrogen released to containment was produced from Zircalloy oxidation, but oxygen from thermolysis and radiolysis was also produced.

For the following calculation, the action to cause PRV opening was assumed to be a fluid transient, where pumps increased the pressure to adiabatically compress and heat hydrogen near the PRV. Even so, the body of this research concludes that an explosion occurred in the TMI RCW system due to fluid transients that exceeded autoignition conditions. Also, the predicted maximum temperatures and pressures are the same, since autoignition occurs at the PRV discharge.

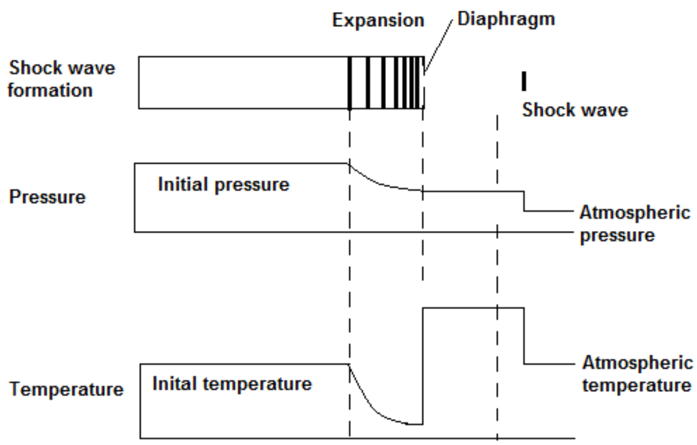


Figure 11: Conditions for a Burst Diaphragm

PRV discharge conditions

There are two limiting models for valve operations[5], which are slow and sudden valve openings. The following calculations do not include reflected pressure wave effects, which would reduce the autoignition temperatures and pressures. Note that reflected wave effects can reduce autoignition pressures by a factor of three to five, where choked sonic flow through the PRV results in detonation waves near the PRV exit that leads into the piping, and resultant shock waves that reflect from the internal walls of the piping and PRV. Initial conditions equal the operating conditions, 575°F and 14.48 MPa, 2100 psig (See Fig.2).

For slow valve opening, steady state sonic flow through the PRV is assumed, where compressed hydrogen is exhausted to air in the discharge piping through the PRV. Assuming initial ambient conditions, the theoretical PRV discharge conditions equal

$$T_{discharge,min} = 0.0833 \cdot (575 + 273) = 434^{o}\mathrm{C} \quad (11)$$

$$P_{discharge,min} = 0.5283 \cdot 14.58\ \mathrm{MPa} = 7.70\ \mathrm{MPa} \quad (1117\ \mathrm{psia}) \quad (12)$$

This temperature and pressure are well above the autoignition point for hydrogen, as shown in Fig. 2.

For a suddenly opened valve, the PRV is assumed to open instantaneously, where a ruptured diaphragm in a shock tube is modeled. This model is shown in Fig. 11, where the pressure drops, and the temperature increases for a suddenly burst diaphragm. Using a graphical method with gas tables from John, conditions for a suddenly opened valve, the theoretical PRV discharge conditions (Eq. 4) equal

$$T_{discharge,\ max} = 1523^{o}\mathrm{C} \quad (13)$$

$$P_{discharge,max} = 0.71\ \mathrm{MPa} \ \ (102.9\ \mathrm{psia}) \quad (14)$$

The theoretical results from Eqs. 11-14 are well above autoignition conditions, and ignition will occur as the hydrogen exits the PRV. Either a detonation or a deflagration to detonation transition will occur, depending on water content in the gases. Accordingly, explosive conditions (Eq. 4) equal

$$T_{explosion,\ max} = 8293^{o}\mathrm{C} \quad (15)$$

$$P_{explosion,max} = 37.1\ \mathrm{MPa} \ \ (5383\ \mathrm{psia}) \quad (16)$$

These calculations provide the mathematical proof for one explosion cause at TMI. However, the complex sequence of events requires discussion to fully evaluate the TMI explosions.

TMI explosions

The first hydrogen release occurred at 06:20 in the PRV discharge piping (Fig. 7), and hydrogen, oxygen, and steam were released to containment, where high concentrations of water prevented hydrogen autoignition during this PRV discharge. Between 06:20 and 07:20, stratification permitted some hydrogen and oxygen to separate in the piping near the PRV. At 07:20, the PRV was manually opened, this hydrogen-oxygen mixture autoignited, and a detonation blew the water out of the pressurized relief tank. Following this first explosion, the PRV remained open between 07:20 and 13:08. Water concentrations in the gas mixture again prevented autoignition in the PRV discharge piping, and while the PRV remained open until 13:08 additional hydrogen, oxygen, and steam were discharged. Between 13:08 and 13:50, hydrogen and oxygen again stratified near the PRV. When the PRV was reopened, a second explosion

[5] Earlier work calculated adiabatic compression temperatures and pressures that would be released through the PRV for slow valve openings. Higher temperature sudden valve openings are also considered in this paper. Final results for either model are the same.

occurred, which exploded down through the PRV piping where a detonation wave blasted out of the pressurizer relief tank into the hydrogen filled reactor building to complete the explosion in the RB.

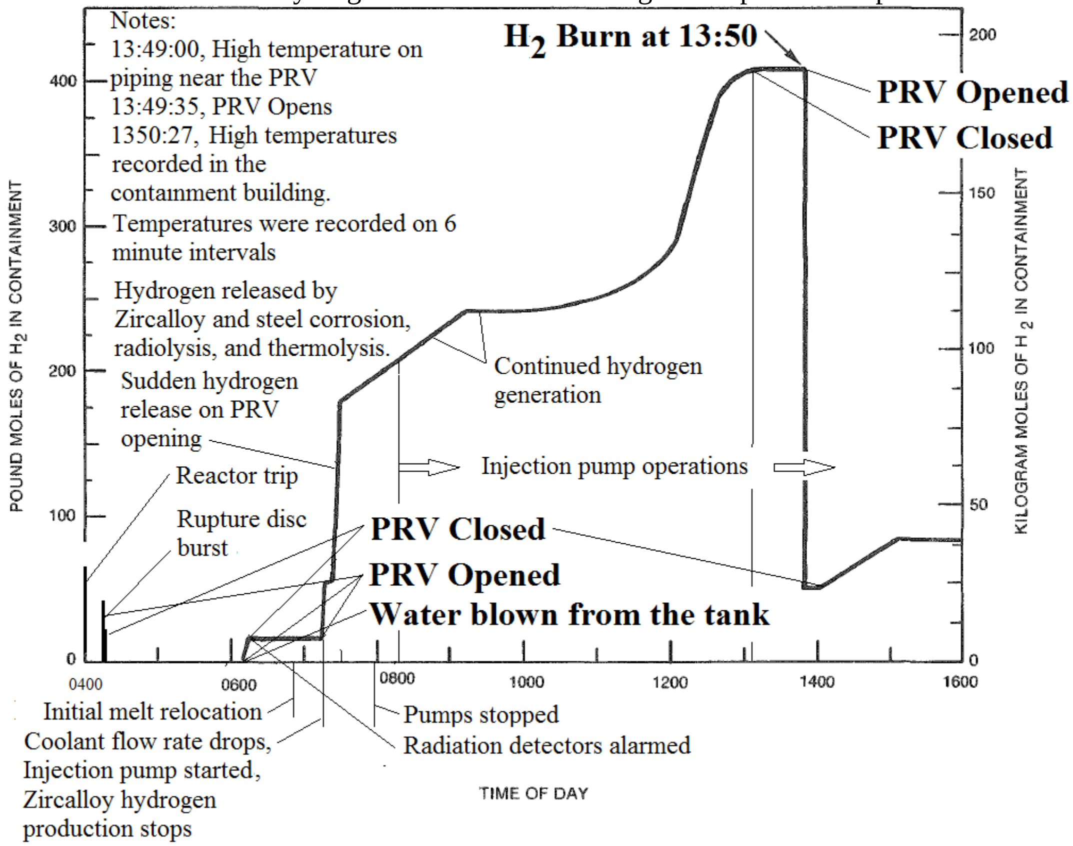


Figure 12: TMI Hydrogen Explosion Sequence (Adapted from Henrie and Postma and NRC)

The first fluid transient explosion

A detonation, rather than a deflagration only, was a necessary condition to burst the water from the tank. A deflagration alone would not have provided sufficient pressure to burst the rupture disc and shoot the water from the tank, as gleaned from Table 1. A detonation was ignited downstream of the PRV in the stratified hydrogen and oxygen, where the detonation wave acted as a spark source to travel at supersonic velocity down to the pressurized relief tank to eject the water. Shielded from the containment building by the pressurized relief tank water volume, detonation waves dissipated before entering the building, and the flammable gases in the building were not ignited during this first explosion. Explosion conditions at the PRV discharge are described by Eqs. 15 and 16.

The second fluid transient explosion

Quantities of oxygen and hydrogen from thermolysis and hydrogen from Zircalloy corrosion accumulated in the piping and the RB, since water was dumped on a molten core. The PRV was open for nearly six hours during these hydrogen processes, and then closed until 13:08 while stratification occurred. When the PRV was reopened at 13:50:00, a flammable source and an open path to containment was available since the pressurized relief tank was empty. That is, the PRV reopened to blast high temperature gases into the piping, and the pathway to the pressurized relief tank was again autoignited (Eqs. 15-16). This second detonation traveled through the PRV discharge piping and into the containment building. Calculations for the expansion of this detonation wave into containment were not performed, but pressures and temperatures lower than those on the PRV discharge piping are expected.

If operators had not controlled the accident the full core could have melted instead of half of the core, where a full meltdown could have resulted in a larger containment building explosion that paralleled the

Fukushima explosions. Even so, NRC reports conclude that the TMI containment would not have breached.

Figure 13: TMI Damages (Public Domain, Henrie and Postma, NRC)

An explosion rather than a fire

To date, theory stated that a fire occurred at TMI, and stating here that there was an explosion is a major challenge to accepted theory. Previous theory was consistent with all publications that were based on work by Henrie and Postma. Even this author assumed that there was a hydrogen fire rather than a detonation as well. However, that assumption is challenged here as part of this continuing engineering investigation.

To reach this conclusion, combustion equations were performed as the next steps of this ongoing research, and the explosion theories for TMI and Fukushima seemed inconsistent. Further research was performed to better understand these complex accidents. In other words, the TMI combustion accident was reinvestigated, and Fig. 12 was developed in accordance with available published data.

Explosion measurements

Of great importance, an explosion pressure spike was measured in the control room, which indicated that a blast occurred in the RB. A "double thump" was heard by several personnel. That is, an explosion was autoignited as the hot gases burst from the pressurizer relief tank, where the thumps were the auditory, low frequency, vibration response from the concrete containment structures, caused by the measured explosion in the building and a reflected pressure wave due to this explosion. According to an NRC report, the TMI containment building pressure spiked, such that "The chart shows that, on March 28, 1979, at approximately 13:50 hours, two peaks occurred. The narrow range goes off scale and the wide range peaks at about 28 psig (0.2 MPa)". The narrow pressure peak indicates an explosion, where momentary pressures and temperatures approximately equaled 37.2 MPa (5393 psia) and 8293°C (Eq. 4). In short, measured explosion pressures that were originally dismissed by investigators provided an extremely valuable insight into the TMI course of events.

The logical argument is simple: since an explosion pressure occurred, there was an explosion, but this connection had not been previously reasoned. This conclusion changes the results of this investigation, where a TMI explosion rather than a fire occurred. Also note that autoignition conditions would have been lower, since reflected waves reduce autoignition temperatures and pressures. In short, thermal-fluid transients ignited hydrogen in the TMI RB. Also note that the pressurizer relief valve (PRV) piping pressures for the first explosion were not measured, since the blast occurred inside the piping, and did not reach containment due to water in the pressurizer relief tank.

An evaluation of the TMI reactor building explosion

This conclusion that an explosion rather than a fire occurred at TMI is a major finding, and requires further discussion. Henrie and Postma concluded that there was a fire only, due to the observed damages in the building. Their report stated that, "Mechanical damage caused by the pressure pulse was minimal. However, as shown In Fig. 13, 55-gallon drums were partially collapsed by the external pressure. Two of the drums suffered little distortion, and it can be concluded that they were either full or not sealed. Also shown in Fig. 13 is an air duct which was not damaged by the pressure pulse. Numerous other pictures of air ducts are available and in no case is observable mechanical damage apparent. The drums were not damaged predominantly on one side or tipped over by the pressure pulse. This drum damage and lack of duct damage is consistent with a pressure pulse that developed over seconds (i.e., from a deflagration) but is not consistent with the passage of a detonation wave. This supports the view that a detonation did not take place in TMI-2". Their engineering conclusion based on these statements was their proof of deflagration.

As a rebuttal by this author, consider their photo, and contrary to their statement the drum is, in fact, damaged on one side, which indicates an explosion. With respect to the lack of duct damages, no calculations were provided to support their conclusion, where the duct would have been considerably stronger than the drums due to the difference in wall thickness and bolted flanged construction of the duct. For example, heavy duty drums have wall a thickness of 1.5 millimeters and standard drums are 0.09 millimeters thick. By comparison, Schedule 5S piping that is typically used in flanged duct construction has a 2.77 mm wall thickness. Since the duct diameter is slightly smaller than the drum diameter in Fig. 13, the strength of the duct is expected to be nearly twice the strength of the drum with respect to collapse resistance, which is proportional to the explosive load.

Once Henrie and Postma concluded that a fire occurred, they back-calculated burn conditions from available data. They stated that, "Determining hydrogen concentrations from the rate of pressure rise and flame propagation velocities is qualitative at best". They calculated that the flame front travelled at 9 meter/second at 706°C. Only four different measured temperature locations were available at the time of the explosion (13:50:35), which indicated temperatures between 96°C (at the PRV discharge) and 52°C (on pumps in the plant). These temperatures were used as the calculation basis, where these temperature measurements were within a minute of the explosion and were only measured every 6 minutes.

This author provides a significantly different engineering conclusion, where detonation rather than deflagration is considered to be the combustion event. The only concrete evidence was the drum and duct damages, which is rebutted here, where damages to a drum were inadequate proof of a deflagration. There were no temperature measurements to prove or disprove that a detonation or deflagration occurred, and pressure measurements proved that an explosion occurred. Even so, their comprehensive report served as a technical baseline for this TMI explosions research, where the goal of this research is to further advance the understanding of complex explosion accidents.

After the explosions subsided

The building gases burned to flame extinction, where the gas density and volume conditions were inadequate to support a detonation. After the burn stopped there was insufficient oxygen in the building to support combustion. To support this statement, calculations were performed for this paper, using measured oxygen and hydrogen concentrations obtained from Henrie and Postma's paper, and the average hydrogen concentration in the building with respect to air equaled 2.7% on combustion extinction. This concentration is below the 4% explosion limit for hydrogen ignition. Consequently when the PRV was subsequently opened during RCW system venting, there was insufficient oxygen in the containment building and piping to cause further hydrogen explosions.

Venting of hydrogen from containment commenced four days after the accident, where hydrogen recombiners operated for a month to remove hydrogen and oxygen. Residual hydrogen was vented to atmosphere six months later.

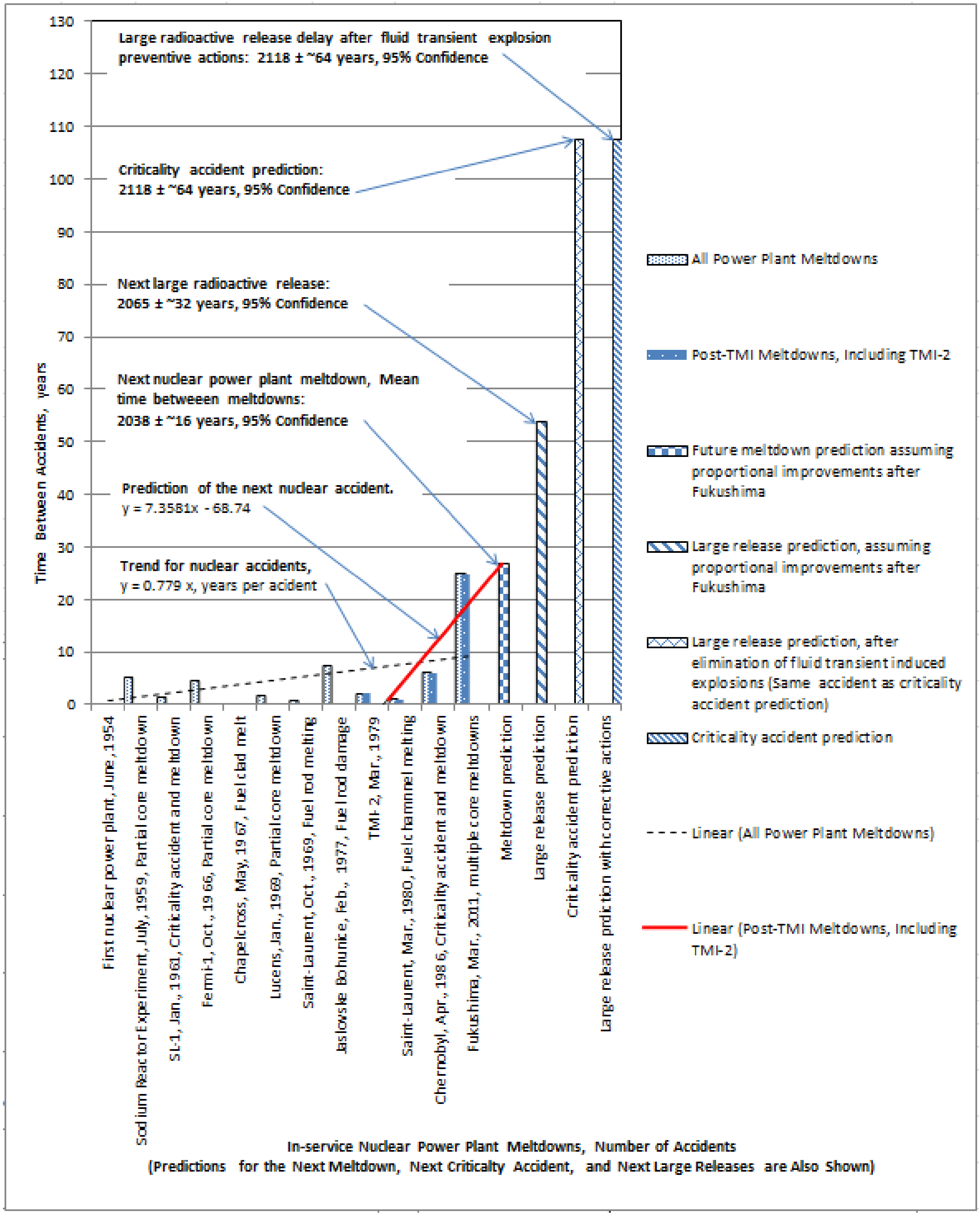


Figure 14: Nuclear Power Plant Accident Evaluations (Leishear [15])

TMI-2 Lessons Learned

Numerous lessons were learned from TMI-2 to improve reactor safety, but the primary lesson with respect to this research was the implementation of probabilistic risk assessment (PRA). PRA uses probability and statistics to analyze the processes and equipment in a nuclear power plant to prove that the plant is safe to operate. Prior to TMI-2, a PRA study proved that a small break, loss of coolant accident was more important to reactor safety than a large double guillotine pipe break, which was then believed to be the most important reactor system failure. That PRA was ignored by regulators and operators, and the TMI-2 meltdown thrust PRA into the reactor regulations. By law, PRA is now used for all reactor designs.

In fact, U.S. regulations require that a PRA must prove that the core damage frequency (CDF) for meltdowns and fuel damages must be less than one accident in 10,000 years, and that the frequency of a large radioactive release (LRF) must be less than one time in 100,000 years. The TMI-2 type meltdown was one type of CDF, where smaller damages to a single fuel rod, multiple fuel rods, or other reactor core internals also constitute CDFs, or meltdowns. The Fukushima and Chernobyl explosions define LRFs. Similar explosion issues maybe expected in some future reactor designs, where this new explosion technology has not been considered in most cases.

The Urgency of This Research

Using the same probability and statistics theories that are used for PRA, the next nuclear accident can be predicted (Leishear [15]). If PRA is acceptable to predict reactor safety, then PRA is acceptable to predict accidents. The calculation results for accident prediction at 95% confidence are shown in Fig. 14, and the next nuclear reactor meltdown is predicted to occur between now and 2038 with a one in two probability of a large radioactive release at the same time.

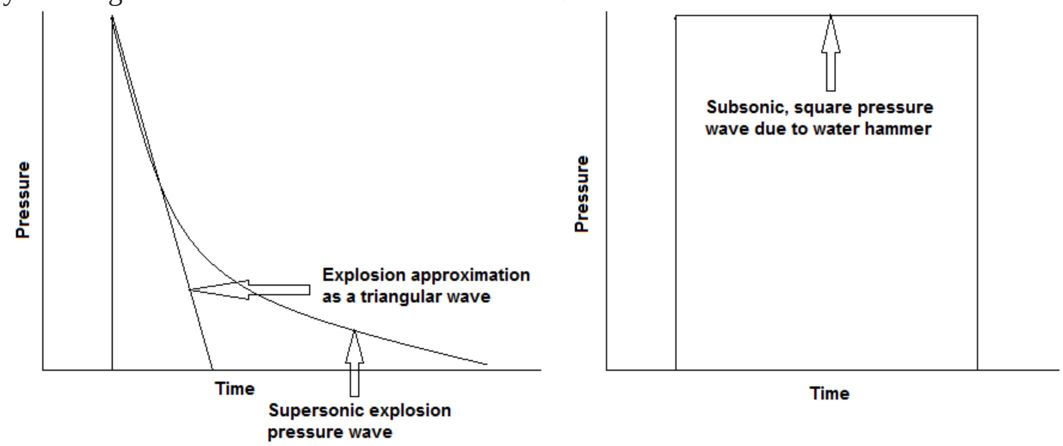


Figure 15: Comparison of Explosion Shock Waves to Water Hammer Pressure Waves

Figure 16: The Fukushima Explosion, 2011 (NEA)

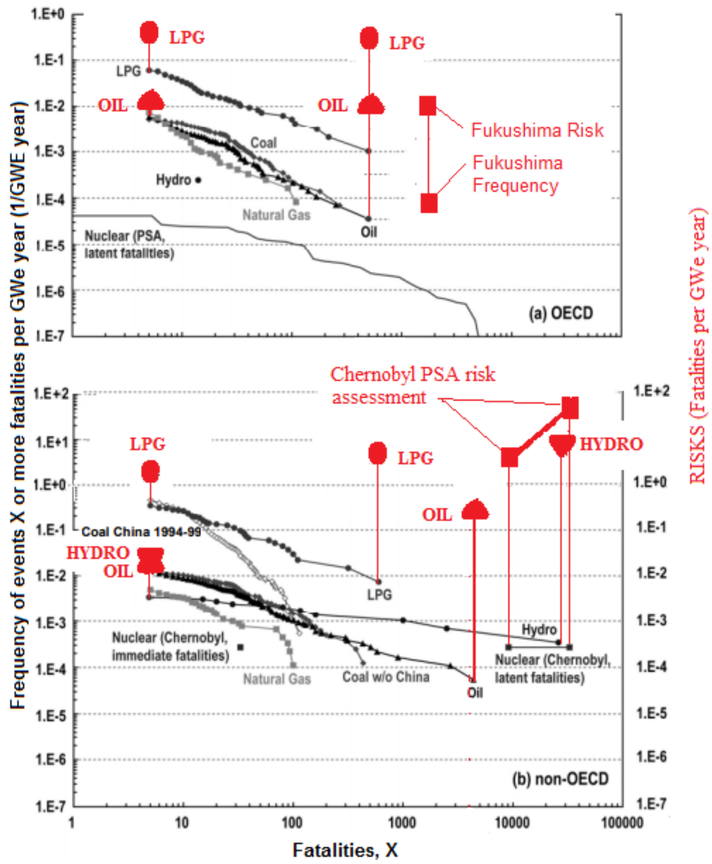


Figure 17: Frequency vs. Consequences and Risk vs. Consequences for Severe Accidents
(Leishear [14])

Reactor Accidents

One may argue that reactor designs are so safe that another accident can never occur, but the facts do not support such a position. The facts to support this nuclear accident prediction follow.

1. 20 CDF accidents have occurred in the nuclear industry.
2. 10 CDF accidents have occurred in the nuclear power industry since 1954.
3. 19 criticality accidents have occurred in the nuclear industry.
4. 3 CDFs have occurred since TMI-2.
5. The 2018 accident prediction was based on CDFs and LRFs that occurred since TMI-2.
6. A radioactive release would be predicted to occur years earlier (2021) if all 10 power plant accidents were included in the probability and statistics calculations, and this calculation was considered to be unacceptable, where many lessons learned have been implemented since TMI-2.
7. The effects of lessons learned from Fukushima may affect this meltdown prediction, but cannot be concisely quantified. An implicit assumption is that Fukushima Lessons Learned are as effective as TMI-2 Lessons Learned with respect to reactor safety improvements.
8. Prior to every previous meltdown and large radioactive release there has been a common belief that a nuclear accident cannot occur.
9. Nuclear accidents continue to occur.
10. We do not know what we do not know.
11. In DOE parlance, this problem constitutes a potential inadequacy in the safety analysis, where reactor designs and operations are presently unsafe.
12. In general, nuclear power plant safety is comparable to safety in other industries. For decades nuclear plants have been promoted as being far safer than other industries, but those claims were based on the frequency of accidents. Using that criteria, the Fukushima accident is equivalent to

the San Bruno pipeline explosion that killed six people – San Bruno was tragic, but the impact was far less than Fukushima (Figs. 4 and 16). Using appropriate risk values instead of frequency values shows the near equivalence of reactor safety compare to and other industries (Fig. 17).

Reactor Safety Analysis

Reactor Safety Analysis is affected by this research, where another finding of this research is that a LRF of 1 in 100,000 years cannot occur if the CDF equals 1 in 10,000 years (Leishear [16]). Research shows that fluid transients provide a connection between meltdowns and radioactive releases, i.e., LRFs are coincident to some CDFs. Accordingly, NRC PRA regulations provide disparate rules, and the safety analysis of reactors in the U.S. reactor fleet may be incorrectly performed, and this safety issue also affects countries that use NRC regulations. This problem also constitutes a potential inadequacy in the safety analysis, where reactor designs may or may not meet regulatory requirements, since all safety analyses were not reviewed for this research.

This major safety issue with respect to fluid transient explosions has been brought to the attention of the U.S. Nuclear Regulatory Commission (Leishear [17]), and they provided responses that disagreed with Dr. Leishear's findings (Boyce [18]). However, Dr. Leishear has since published additional proof to disprove their objections. Even so, the NRC and Dr. Leishear have reached a point of unresolved disagreement, where further research is required to convince the NRC, IAEA, and NEA agencies of the validity and applicability of this research. Otherwise, deaths will continue, where 141 deaths were attributed to relocation efforts following Fukushima, and no deaths were attributed to the TMI-2 accident.

How can current and future reactors be deemed safe if current nuclear reactor operations and accidents are not clearly understood? Explosions can be stopped.

Background of Gas Pipeline Explosion Research

Since the San Bruno pipeline explosion will be used to initially investigate explosion complexities, a brief review of research to date is appropriate. This accident has been selected to explain explosion phenomenon, since the accident has been extensively investigated, and extensive data is available for evaluations. Hydrogen explosions could have been investigated instead, but there is insufficient data for model validation.

Although not yet published, a basic analysis of the San Bruno explosion has been completed by this author. The extent of the explosion is shown in Figs. 18 and 19. Using the Leishear Explosion Theory, the accident can be explains as follows, where the supporting data is shown in Fig. 20.

Figure 18: The San Bruno Explosion That Killed 8 People, 2010 (PHMSA)

Figure 19: San Bruno Gas Pipeline Fire Damages that Killed 8 People

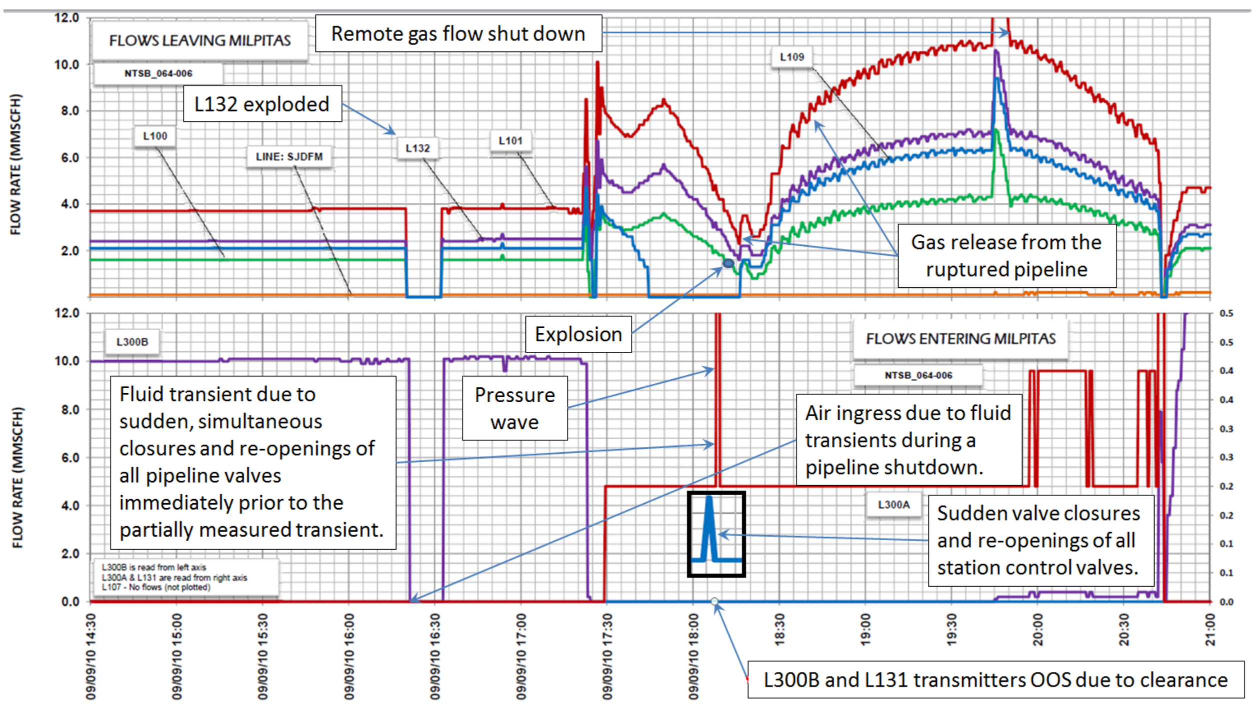


Figure 20: San Bruno Explosion Records

Use of Previous Research for Computer Models

Previous research for water hammer and gas pipeline research will be used to validate explosion models. Although water hammer induced fatigue is well understood, there is a deficiency to the theory.

Dynamic load factors (DLFs) were proven to have a maximum value of 4, as described by the Leishear Stress Theory. This DLF can be reduced by damping and wave speeds, but these effects have not been thoroughly investigated and are particularly important to explosion pressure waves during fatigue.

Small explosions damage piping in nuclear power plants, but there is little experimental research that can be referenced for this type of damage. However, Dr. Leishear has performed extensive research on fatigue due to water hammer (Leishear [19-21]). Explosion waves can be represented as triangular waves for comparison to square water hammer waves. If one wave form is understood in a pipeline the other is explicitly understood, since fundamental vibration equations relate the two types of waves. Accordingly, water hammer waves that destroy water mains and other piping systems provide an understanding of fatigue failures due to explosions. Even so, a recent discovery by Dr. Leishear shows that the fatigue properties of pipes remarkably decrease when piping surfaces are grit blasted for coating preparations (Leishear [22]).

Limited experimental data for fluid transient explosions is available in the literature. The physics of piping explosions are very complex, and applicable models are unavailable in the literature. Again, this research is first-of-a-kind. Pipes have shredded like paper firecrackers at Hamaoka and Brunsbuttel, and Hamaoka will be partially modeled in this research. However, the Hamaoka explosion not only ruptured the piping, but pipes bent considerably. Accordingly, a simpler model is preferred for investigation.

Five to ten explosions due to deaths occur every year (Fig. 20). A perfect example of simplified explosions can be found in gas pipeline explosions that are not subject to bending. The San Bruno explosion that killed eight people will be modeled to validate the combustion and structural programs used to model piping ruptures – extensive experimental data is available in the literature for comparison to models (Leishear [23]). Even so, engineering judgement will be required to quantitatively assess the explosion results (Fig. 21). Repairs were in process on a 30 inch diameter pipeline that was nearly 50 miles long. During repairs, the pipeline was depressurized, which resulted in the ingress of air into the pipeline, and this air moved 39 miles downstream to collect at a low point in the pipeline, where air is lighter than natural gas, which predominantly consists of methane. Two hours after the air ingress, repairs were in process when all of the pipeline gas transmission valves were inadvertently slammed shut. This slamming induced a pressure wave that travelled at a near sonic velocity downstream in the pipeline until this pressure wave contacted the air in the pipeline at San Bruno 39 miles away. The pressure wave increased the pressure and temperature of the air, which in turn autoignited methane and caused the explosion and resultant crater.

For this accident, official reports claimed that the energy release caused the crater, but calculations shown in Fig. 20 clearly prove that an ruptured pipeline cannot develop a crater unless a methane detonation occurs. An alternative theory to explain the crater is that, the methane burrows hole to the ground, and methane then burns as a fire, i.e., no explosion occurred at all. This alternative opinion does not fit the facts - a burrowing action could not possibly create a 72 by 26 foot trench – a circular crater or small irregular shaped crater would be formed. In other words, fluid transients caused the San Bruno explosion, and this research will investigate that accident to technically background and validate nuclear plant explosion modeling.

Background of Water Hammer Research

Water hammer, by itself, has little to do with nuclear power plant explosions but the comparative simplicity of water hammer modeling provides a solid foundation to provide model validations for nuclear power plant piping breaks. An added benefit is that water main breaks will be better understood, where Dr. Leishear is currently the foremost world expert in pipeline breaks due to water hammer, as evidenced by his ASME textbook and many publications (Fig. 21). The fracture mechanism is identical for water pipes or nuclear system pipes – only the nature of the applied load changes. All in all this interrelated research will benefit multiple industries while validating models for nuclear power plant explosions.

That is, this research will be directly responsible for environmental disasters and deaths in the nuclear industry, and while validating nuclear system models other models will contribute to the prevention of deaths and multi-billion dollar damages throughout industry. Bear in mind that these supplemental models are essential for the validation and proof of principal for nuclear power plant explosion prevention. In other words, this research is not investigating multiple tasks, but is investigating a single catastrophic problem with respect to nuclear reactor safety – one mission – one goal – stop nuclear power plant death and destruction. Specifically, Dr. Leishear is the Project Manager responsible for generating a new ASME Code to address fluid transient damages in pipelines, and the research proposed herein resolves question with respect to the implementation of that standard in addition to validating explosion models.

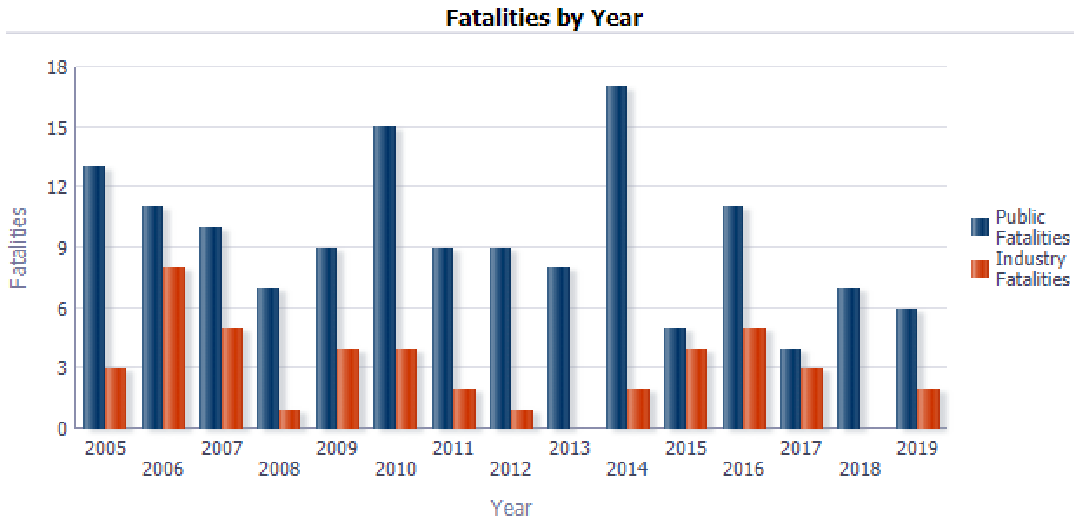


Figure 21: Gas Pipeline Fatalities (PHMSA)

Figure 21: Pipeline Ruptured Due to Water Hammer

The Effects of Previous Research on Project Budget and Schedule

All of the explosion studies, all of the explosion research, and all of the resultant explosion publications have been performed for a single purpose – to stop nuclear power plant explosions. Past performance may not typically equate to budget and schedule compliance, but in this case, years have been dedicated to ensure that this next phase of research can be completed quickly with a clearly defined scope and budget.. I, Robert Leishear, ask that the next phase of this research be supported by DOE to ensure project success. I plan to go forward whether I receive DOE support or not, but the work will take longer without the appropriate contract opportunities with Fluent and SimuTech, and lives will be lost due to such a delay. To demonstrate my abilities to successfully manage projects, I requested references from successful people, as follows.

LETTERS OF RECOMMENDATION

Several Letters of Recommendation are presented in Appendix A to describe a representative cross section of success. Each reference was associated with a different part of Dr. Leishear's career, where all of these career experiences engage skills that are essential to the successful project management and research that will be required for this project. Authors for these Letters are briefly mentioned as follows.

1. **Wyatt Clark, SRNS Senior Vice President of Operations** and Previous Acting Chief Operating Officer for Savannah River Nuclear Solutions (SRNS), which is a DOE nuclear material processing and research facility in South Carolina. At different times over 24 years, Dr. Leishear worked for Wyatt Clark in his positions as Engineering Manager, Operations Plant Manager and Senior Vice President.
2. **Bradley Walker, Y12 and Pantex, Senior Engineering Director** and previous Chief Engineer for Y12, where Y12 and Pantex are facilities of the DOE nuclear weapons complex. Dr. Leishear worked with Brad Walker to eliminate nearly 20 years of pipeline breaks in a safety class fire suppression system at the Pantex facility.
3. **Travis Knight, Director of the Nuclear Engineering Department and Professor for the University of South Carolina**. Dr Knight is my Ph.D. Dissertation advisor to support my ongoing research and new theories that explain fires and explosions in nuclear power plants.
4. **Mary Grace Stefanchik, ASME Press Publications Manager** (American Society of Mechanical Engineers). I worked and contracted with Mary Grace Stefanchik when Dr. Leishear wrote and published an engineering textbook on "Fluid Mechanics, Water Hammer, Dynamic Stresses, and Piping Design". This book presented the Leishear Stress Theory, which is a new theory that was invented to explain why pipes break, where the piping failure causes of water main breaks, and piping failures throughout industry, have been misunderstood for more than a century.
5. **Billy Giddings, SRNS Project Manager** and previous Engineering Manager for the Savannah River National Laboratory (SRNL), Pilot Scale, Fluids and Heat Transfer Testing Laboratory. Billy Giddings served as a direct manager for Dr. Leishear as he performed fluids and mass transfer pilot scale research, when Dr. Leishear worked as a Research Engineer for SRNL.

PERFORMANCE SUMMARY

An extensive effort has been performed during years of volunteer research at great financial burden – thousands of hours were invested with total costs of approximately $130,000. That is, multi-disciplinary studies have been completed over many years to provide the broad understanding required to undertake and succeed in this extremely complex research project. This effort should be seriously considered during proposal evaluation – an extraordinary self-commitment has been made to stop explosions in nuclear reactor facilities to stop deaths, equipment damages and environmental damages. My driving goal has been public safety, which is also a goal of the US Department of Energy. Dr. Leishear's past performance accomplishments can be summarized as follows.

Dr. Robert A. Leishear, Ph.D., P.E.

- Managed large and small DOE contractor projects of magnitudes equivalent to this project and published numerous new, peer reviewed theories, which resulted from those projects.
- Performed finite element modeling and directed finite element modeling research by others.
- Performed experimental research and directed technical staff.
- Published an ASME book and 80+ other engineering publications.
- Invented a new theory to prove that the next nuclear accident is imminent, and proved that a large radioactive release like Fukushima may occur at the same time.
- Invented a new theory, the Leishear Explosion Theory, to explain and stop nuclear power plant explosions, which kill people, damage property, and damage the environment..

- Used the Leishear Explosion Theory to explain gas and oil pipeline explosions, which kill 5 to 10 people per year in the U.S.
- Invented a new theory, the Leishear Stress Theory, to explain piping breaks.
- Used the Leishear Stress Theory to stop 40 years of piping breaks, where more than 200 piping breaks were misdiagnosed for decades.
- Used the Leishear Stress Theory to explain water main breaks, which presently costs 13 billion dollars per year in the U.S, and these water main breaks have been misdiagnosed for more than a century.
- Used the Leishear Stress Theory to explain piping breaks in U.S. reactors, which have been misdiagnosed for 70 years.
- Invented a new theory to explain the reduction in fatigue properties due to grit blasting, which explains premature failures of nuclear plant piping subjected to small explosions.
- Invented new theory to improve the life of 1.5 million dollar pumps, which are used in DOE facilities, and failures were misunderstood for decades.
- Invented a new theory to explain vibration resonance, and this theory was used to make a robotic arm work properly to sample one million gallon, radioactive liquid waste storage tanks. Vibration resonance has been misunderstood for more than a century.
- Invented new theory to explain the mixing processes in nuclear waste storage tanks.
- Invented new theory to explain two phase mass transfer processes in nuclear waste sludge, which is a highly viscous mixture of nuclear wastes from nuclear fuel reprocessing.
- Served as a Research Engineer, Project Engineer, Design Engineer, Test Engineer, Metrology Engineer, Shift Engineer, and Quality Assurance Engineer.

APPENDIX A: RECOMMENDATION LETTERS

Department of Energy
Nuclear Energy Technology Laboratory

Nuclear Power Plant Fire and Explosions Research Grant

I have had the privilege of working with Dr. Robert Leishear for many years, on multiple projects. As a result, I strongly encourage his consideration for a DOE grant to investigate "Fires and Explosions in Nuclear Power Plants."

Dr. Leishear's work has been transformational and his innovative approaches to applied research have resulted in significant savings as noted below:

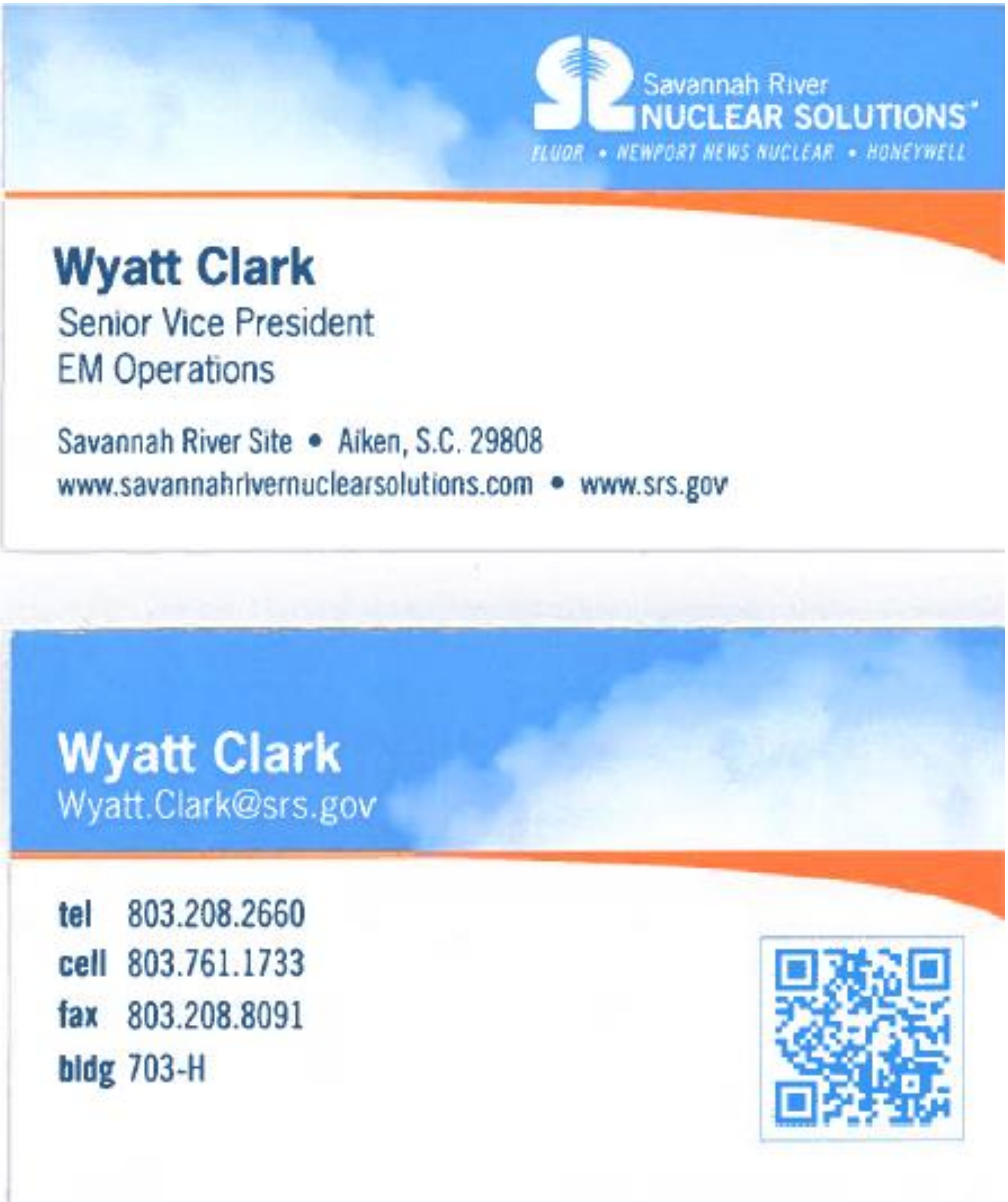
1. Dr. Leishear researched and developed a solution that would eliminate hundreds of piping failures, spanning over 40 years at the Savanah River Site. Based on his research, he authored an engineering textbook for the American Society of Mechanical Engineers. His innovative solution has the potential to eliminate water main failures, a multibillion-dollar problem in the US.
2. Dr. Leishear researched and implemented a pump design that saved twenty-five million dollars at the Savannah River Site. This was especially significant since these pumps were used in highly radioactive waste processing and a failure represented a repair / disposal challenge. His work was documented in a Six Sigma project.
3. While working at the Savannah River National Laboratory, Dr. Leishear designed a robotic arm to drill and deliver radioactive samples. Sampling a radioactive million-gallon tank for regulatory closure required his innovative approach.

In addition to the applied solutions, Dr. Leishear has contributed to the technical community with over 75 technical publications.

His recent formal education advancements, i.e. Nuclear Engineering PhD and studies in Engineering Law, have strengthened his knowledge of reactor operations and design. As a result, he is highly qualified to identify applied solutions for the nuclear power industry.

Sincerely,

Wyatt Clark
Senior Vice President, Environmental Management Operations
Savannah River Nuclear Solutions
O: 803-208-2660
M: 803-761-1733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To the National Energy Technology Laboratory,

I would like to recommend Dr. Robert Leishear for the DOE research grant for his work on "Stop Fires and Explosions in Nuclear Power Plants". I have known Dr. Leishear for several years through our work on the ASME B31.3 Process Piping Committee. Some of our early conversations revolved around our challenges in working the piping issue at our respective sites at Savannah River and the Y-12 National Security Complex. I learned early on in my Code Committee participation that Dr. Leishear was a valuable resource in the fluids engineering arena to our Committee.

However, last year I called on him to directly participate in solving a very complex fluid problem I was experiencing at our sister facility at Pantex in Amarillo, TX. After multiple discussions, I brought Dr. Leishear to Pantex to investigate potential water hammer issues.

In the weeks we worked together with other Pantex engineers, my previous perspective of Dr. Leishear's knowledge in fluids engineering grew exponentially. I watched him eagerly mentor young engineers in the basics of fluids engineering. As Dr. Leishear successfully completed his work for us, I was astonished with his knowledge and compassion for this field. Therefore, I highly recommend Dr. Leishear for consideration in this research endeavor.

Regards,

Brad Walker, P.E.

Senior Director – Mission Engineering, Consolidated Nuclear Security, LLC

Oak Ridge, TN

865-574-893

UNIVERSITY OF SOUTH CAROLINA
DEPARTMENT OF MECHANICAL ENGINEERING

Date: 6 December 2018

TO: Department of Energy, Nuclear Energy Technology Laboratory

RE: Nuclear Power Plant Fire and Explosions Research Grant

I strongly support Dr. Robert Leishear's receipt of a DOE grant to research "Fires and Explosions in Nuclear Power Plants". He has dedicated the past several years toward comprehensive studies of the background related to this research, and he has extensive industrial and research experience to ensure project success.

In addition to writing a dozen peer reviewed publications on nuclear power plant fires and explosions, Dr. Leishear's studies over the past three years include:

1. All of the classes needed to complete a PhD in Nuclear Engineering.
2. More than 30 additional courses from around the world, which included International Nuclear Law, combustion, and explosions, as well as computer code courses for designing nuclear reactors and reactor cooling systems.

His studies prior to this research also lead to an understanding of fires and explosions in nuclear power plants, where studies included:

1. ASME piping and pressure vessel design courses.
2. A PhD in Mechanical Engineering which focused on fluid dynamics and failure analysis of pipe systems.
3. Qualification Cards and Oral Boards at DOE facilities, which taught all of the infrastructure, safety, and nuclear processes for nuclear fuel reprocessing, nuclear waste processing, instrumentation calibrations, and Shift Technical Engineer responsibilities.
4. Practical experience as an electrician, Journeyman Sheet Metal Worker, and welder.

As a research engineer at Savannah River Site, Dr. Leishear applied innovative concepts to save that DOE facility more than 50 million dollars during his career. As a research engineer for Leishear Engineering, LLC he recently solved a safety class problem related to the fire protection system at Pantex, which is a nuclear weapons production facility. Even so, his recent efforts have been directed toward related studies of commercial nuclear power plants which have the potential to cut costs and improve safety.

If you have any questions regarding this matter, please feel free to contact me by telephone at (803) 777-1465 or by e-mail at twknight@sc.edu.

Sincerely,

Travis W. Knight
Professor and Director
Nuclear Engineering Program

ASME PRESS

Two Park Avenue, New York, NY 10016 ▪ Telephone 1-212-591-7962 ▪ Fax 1-212-591-7292

August 31, 2018

Department of Energy
Nuclear Energy Technology Laboratory

Re: Reference and Support to Secure a DOE Research Grant

Dear Sir/Madam:

I write on behalf of **Robert A. Leishear**, in support of his research proposal to the DOE for a grant to fund research, which will "Stop Fires and Explosions in Nuclear Power Plants." PhD research will be performed by R. A. Leishear at the University of South Carolina, in association with an explosives test facility in Arkansas. His research has discovered a common cause for explosions at nuclear reactor plants, which include the Fukushima hydrogen explosions, a hydrogen explosion at Three Mile Island, and hundreds of small explosions in U.S. nuclear reactors that have been misdiagnosed as water hammer since the 1950s.

Through this letter, ASME acknowledges that in the event this proposal is funded, we would expect our role following the project to include:

- Provide a book publishing opportunity for this research under the ASME Press publishing imprint, pending peer review and other internal ASME approvals.
- This new book will be the latest in a series of three ASME Press books that improve international technology and infrastructure by inventing new theories.
- The previous two books, along with more than 60 ASME Conference and Journal publications, provide a technical foundation for this proposed research, while curtailing an expected trillion dollars in U.S. water main breaks in the next 25 years.

ASME Press looks forward to having the opportunity to publish this important research and supports the funding of this proposal.

Sincerely,

Mary Grace Stefanchik
Manager, Publications Development
ASME Press
stefanchikm@asme.org

Letter of Reference for Research Grant to Improve US Nuclear Facility Safety

August 13, 2018

Dear Selection Committee,

I am writing this letter to give my highest possible recommendation for Dr. Robert Leishear. I have known Dr. Leishear through his work both in the Savannah River National Laboratory, where he served as a Principal Engineer in the Engineering Development Laboratory and as a System Engineer at the H-Canyon Facility at the Savannah River Site. Dr. Leishear's research and diagnostic skills are excellent and has contributed to the successful resolution of many complex matters that spans the gamut nuclear and mechanical technical issues.

Dr. Leishear's engineering work and research performance has been with a fundamental belief that text books and existing theory are tools to develop new theory, rather than restrictive rules for design. Because of this belief, Bob frequently promoted singular dissenting opinions that turned projects arounc and led those projects to success. Resulting from these projects, numerous theories have been developed in areas of expertise to solve complex technical problems. In summary, extensive engineering education, technical training, and practical experience supported million dollars in cost savings to SRS, numerous innovative technical publications, including an ASME text book on Fluid Mechanics, Water Hammer, Dynamic Stresses, and Piping Design, and in teaching of the techniques he has learned and developed to 600 -700 engineers and operators. He has consistently demonstrated the skills needed to identify new solution techniques to complex technical problems that were previously unsolved

I have had the privilege to nominate Bob to the Senior Fellow Engineer position at the Savannah River National Laboratory and had no difficulty obtaining recommendations from Engineering and Operations Management across the Savannah River Site, for whom Bob has interfaced throughout his career. Some of the sentiments provided by these references include opinions I share as it comes to his technical competence and abilities. Bob is a creative thinker, who carefully considers all aspects of technical challenges and many times proposed solutions that are considered "outside the box" and correct. He is committed to knowledge and technical accuracy and gives due considerations and thoughtful recommendations. He communicates effectively on all levels and provides customers with valuable, effective information that can be used to make key decisions. He is one of the hardest working engineers I have ever encounters and is never satisfied with anything less than complete success.

In summary, Dr. Robert Leishear is clearly the best engineering resource I can recommend for research into nuclear facility safety as it applies to fires and explosions and he is well deserving of this grant. I give him my highest recommendation.

Sincerely,

Billy J. Giddings
Project Manager, H-Canyon Operations
Savannah River Nuclear Solutions
Savannah River Site
Building 221-H
Aiken, SC, 29809

APPENDIX B: NUCLEAR POWER PLANTS ARE NOT SO SAFE: A QUESTION OF ETHICS

NERS-19-1132

Robert A. Leishear, Ph. D., P. E., ASME Fellow
Leishear Engineering, LLC, 205 Longleaf Court, Aiken, South Carolina, 29803
Email - leishear@aol.com, Website - leishearengineeringllc.com

ABSTRACT

New research concludes that nuclear power plants are not as safe as they have been published to be for decades. Publications throughout the nuclear industry non-conservatively use available data to promote nuclear reactor safety, and typical presentations of this data are misleading - published models have skewed accident data for decades to present nuclear energy as safer than it is. Also, previous publications do not accurately assess reactor safety with respect to other industries and accidents. In general, models provide engineering guidance and insight to approximate reality, but facts are the true measure to describe reality. A question of ethics arises when facts are replaced with theory to yield misleading and incorrect conclusions with respect to nuclear reactor safety. To continue the use of these previous publications without acknowledging this dilemma represents a breach of ethics.

The major findings of this study follow, and calculations were performed with a 95% confidence level.

1. A meltdown similar to Three Mile Island (TMI-2) with a one in two probability of a large radioactive release may occur at any time, and is likely by 2038.
2. A radioactive release like Fukushima is expected between 2032 and 2065.
3. This predicted radioactive release can be delayed to occur until at least 2054 and 2118.
4. Nuclear power plant accidental deaths are not significantly safer than other industries – when indirect deaths are considered - but accidental deaths are comparable to other industries.

As a result of technological advances presented here, an improved explanation of nuclear power plant safety is provided to better understand radiation business dangers.

NOMENCLATURE

CDF	core damage frequency
GWe	gigawatt, electric
IAEA	International Atomic Energy Agency
NEA	Nuclear Energy agency, OECD
NRC	U.S. Nuclear Regulatory Agency
LRF	large release frequency
MWe	megawatt, electric
OECD	Organization for Economic Development and Cooperation
PSA	probabilistic risk assessment
TMI	Three Mile Island
WHO	World Health Organization
UNESCO	United Nations Educational, Scientific and Cultural Organization
x	number of accidents
y	number of years between accidents
σ	standard deviation

KEYWORDS
Chernobyl, TMI, Fukushima, explosion, reactor safety.

INTRODUCTION

Probability theory has been used by others to incorrectly evaluate and misrepresent the safety of nuclear power plants, and the focus of this study is to use that same probability theory to prove that reactor safety is improperly presented in previous literature. First of all, graphic accident frequency publications for single reactor operations are used to imply that the same frequencies apply to the world-wide reactor fleet, but the accident frequencies for the fleet are much higher than publicized. Secondly, frequencies are used throughout the nuclear industry to publicize reactor safety, but risks are more appropriate, and risk evaluations prove that previous publications are misleading. Finally, in-service nuclear accidents are typically neglected when predicting future accidents.

To understand these complex interrelated issues, accidental meltdowns, accidental radioactive material releases, and accidental deaths require consideration. Although data from numerous reactor accidents support this research, the primary reactors of discussion are Three Mile Island, Unit 2 (TMI-2), Chernobyl, Unit 4, and Fukushima Daiichi, Units 1 through 4, where major accidents drastically changed the nuclear industry. Even so, numerous reactor meltdowns, reactor criticality accidents, and reactor system explosions are excluded from this study, since nuclear power plant large-scale accidents and accidental deaths bound the focus of this study. A summary of nuclear accidents is first required to introduce frequencies, risks, probabilistic safety analysis (PSA) models, and ethics.

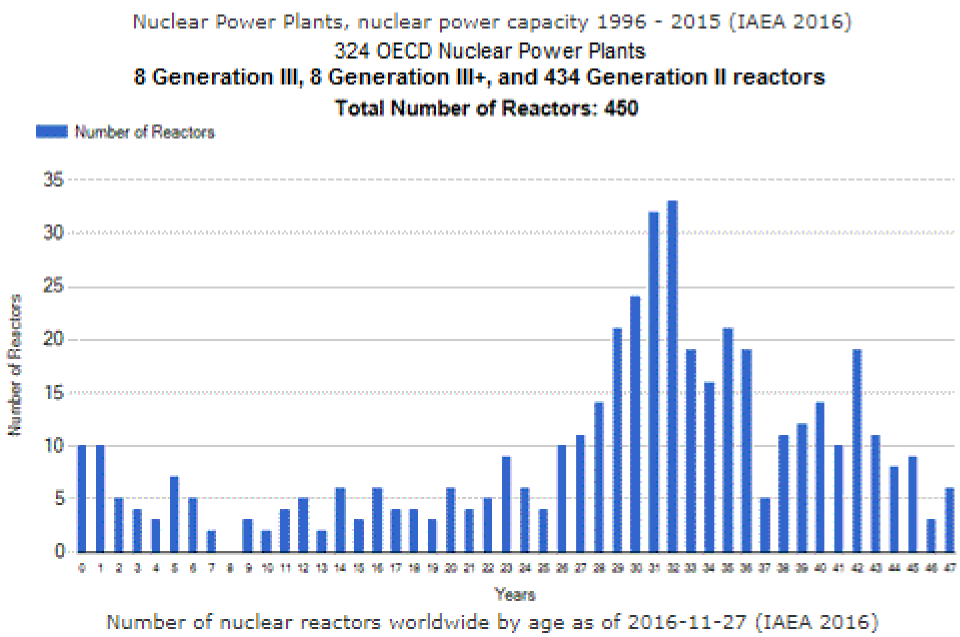

Figure 1: Operating Nuclear Reactors (Adapted by permission of the European Nuclear Society [1]) http://www.euronuclear.org/info/encyclopedia/n/nuclear-power-plant-world-wide.htm

PRIMARY ACCIDENT DESCRIPTIONS

Three of the primary accidents of concern to this study require a brief summary, i.e., TMI-2, Chernobyl, and Fukushima. These accidents and their causes were detailed in a previous paper, supported by extensive references (Leishear [2]). That paper is the technical basis for the following conclusions with respect to these accidents.

1. These accidents had independent causes, but each experienced reactor meltdowns. Chernobyl contained the only reactor involved in these three accidents that experienced a criticality, which is an uncontrolled release of energy during uncontrolled nuclear fission.
    a. The TMI-2 accident had multiple contributing causes, e.g., an inadequate safety analysis, inadequate lessons learned process since a similar accident was averted at Davis- where an accident was successfully averted, inadequate operator training where the operators responded in accordance with navy Nuclear training that was inappropriate, a stuck open

valve that emptied the coolant system while the indicators showed that the valve was closed, and inadequate engineering support where the Shift Technical Engineer position was developed to provide full-time technical support during all operations. In spite of difficulties, operators brought the accident under control before a partial meltdown occurred where the fact that a meltdown occurred was unknown for six years. Many changes were incorporated into the nuclear industry following studies of this accident.

   b. The Chernobyl accident had multiple contributing causes, e.g., inadequate training where the operators did not understand their actions when a fuel rod was improperly extracted to result in a nuclear criticality that multiplied the 950 MWe power by a factor of 100 to 500, inadequate engineering training where the engineer in charge of special turbine tests did not understand the effect of his tests on reactor operations, and incompetent management and engineering decisions where safety interlocks were bypassed where managers were sentenced to 10 year prison terms for authorizing those bypasses to meet schedules.
   c. The Fukushima accident had multiple causes, but primarily a 12 meter wave caused by a tsunami swamped the plant and incapacitated normal and backup electrical power sources. Meltdowns occurred in Units 1, 2, and 3 – explosions occurred in Units 1-4. The Safety analysis assumed that a tsunami wave would be 9 meters in height, which was dwarfed by the actual tsunami wave. Accordingly, there were no emergency response plans for this type of accident. Although extensive accident investigations have been performed, repercussions to the nuclear industry are still being addressed, while some nuclear industry changes have already been incorporated.

2. Reactor system explosions occurred during all three accidents that were related by hydrogen autoignition generated from several sources, which included thermolysis, radiolysis, and Zircalloy corrosion.
   a. Thermolysis breaks water down into explosive hydrogen and oxygen when coolant water is added to molten reactor components or a criticality increases reactor water temperatures. Radiolysis breaks water down into hydrogen and oxygen as well. Zircalloy creates large volumes of hydrogen without oxygen when the fuel rod cladding that contains the uranium dioxide fuel pellets chemically reacts with high temperature steam. Hydrogen and oxygen are formed to varying extents from each of these sources in each accident, and sufficient oxygen is required to burn all of the generated hydrogen.
   b. Hydrogen autoignites as a function of temperature and pressure, similar to a diesel engine. When this autoignition temperature is achieved, hydrogen explodes if sufficient oxygen is present. Different explosions occurred in each accident and the extent of each explosion depended on the quantity of oxygen and hydrogen that was present at the time of the various explosions.
   c. Chernobyl experienced two explosions separated by seconds. The first explosion was due to hydrogen and oxygen generated by thermolysis, and radiolysis caused by the criticality. When this explosion ruptured the reactor vessel - that was not designed for high pressure containment - a large volume of hydrogen mixed with air in the reactor building to ignite on contact with molten fuel. This second explosion was on the order of ten times the magnitude of the first explosion, and the blast was estimated to be equivalent to 14 metric tonnes of dynamite.
   d. Fukushima explosions consisted of two types. The first type of explosion occurred when coolant water was added to the molten reactor cores, and thermolytic hydrogen and oxygen exploded immediately – negligible hydrogen from radiolysis was present. The second type of explosion occurred due to thermal-fluid transients and excess unburned hydrogen from Zircalloy corrosion when coolant water was added to the reactor control the meltdown. Large quantities of unburnt hydrogen from Zircalloy corrosion were exhausted to the reactor building that was not designed for accident containment, and continued pumping of water into the reactor system then compressed residual hydrogen gas inside the piping to heat those

gases above their autoignition temperature. When this heated gas was exhausted to the reactor buildings, the buildings exploded and fired radioactive dust to form a radioactive cloud that circled the globe.

e. In terms of the explosion ignition cause, TMI-2 explosions were nearly identical to Fukushima explosions. When coolant water was added to the reactor during the meltdown, a thermolytic explosion initially occurred, which was smaller than Fukushima thermolytic explosions since the core was only partially melted. As the coolant pumps were started, a large volume of Zircalloy corrosion generated hydrogen was released to the reactor containment building. As the pumps continued to operate two different explosions occurred, but both were caused by thermal-fluid transients – gas was heated by compression and exhausted to burn gases in the containment building. The second explosion autoignited the reactor containment building hydrogen that had mixed with air. In fact, a safety valve on the reactor coolant system opened at the same time as this last explosion, which was incorrectly considered to be a fire for the past forty years (Leishear [2]).
f. Since one out of two meltdowns cause explosions and one out of two power plant explosions are caused by fluid transients, preventing the transients by venting reactor systems before starting pumps will prevent half of the large radioactive releases. Even so, more research is required to evaluate this method.

A BRIEF PSA HISTORY

PSA became an important part of nuclear power plant safety and reliability following the TMI-2 accident. Prior to that accident, a PSA calculation showed that a meltdown accident was likely, and the results were ignored at that time. Consequently, PSA methods were validated by accident experience, PSA now plays a mandatory role in the safety analysis for nuclear power plants per U.S. Nuclear Regulatory Commission (NRC) regulations, and NRC regulations are adopted by many countries. PSA uses statistical failure data for specific components and probability theory to combine statistical failure analysis to predict the overall safety of a nuclear plant.

PSA is applicable to nuclear reactors that include Generation I, II, and III designs. Many Generation 2 designs are still in service, but their production stopped in the late 1990's. Generation II designs include the TMI-2 pressurized water reactors (PWR's), the RBMK at Chernobyl that is a Russian designed PWR, and the boiling water reactors (BWR's) at Fukushima. A majority of the 150 operating reactors are Generation II designs. Generation III designs are presently under present or later construction, and Generation IV designs are future designs. All of the designs ultimately produce steam by different methods to drive steam turbines to create electrical power, with an average power of 1150 MWe (1.15 GWe, Nuclear Power Plants, World-wide, European Nuclear Society, Brussels, Belgium, 2019). The 2016 number of in-service generation II and III reactors are shown in Fig. 1.

PSA applies probability and statistics to model the risks associated with accidents. PSA calculated risks equal the frequency times the consequence, such that

$$\textit{Risk = The accident frequency multiplied times the consequence of the accident} \tag{1}$$

To continue this discussion, some terms require clarification. Reactor design frequencies or risks are associated with discrete, individual reactors. Fleet frequencies or risks are associated with the world-wide fleet of nuclear reactors. Fleet and reactor design risks are further delineated by the adjectives PSA and in-service - PSA frequencies or risks are associated with theoretical, statistical calculations for accidents, and in-service frequencies or risks are associated with actual accident conditions that express real conditions, or historical trends. As one factor of risk, frequencies are considered next.

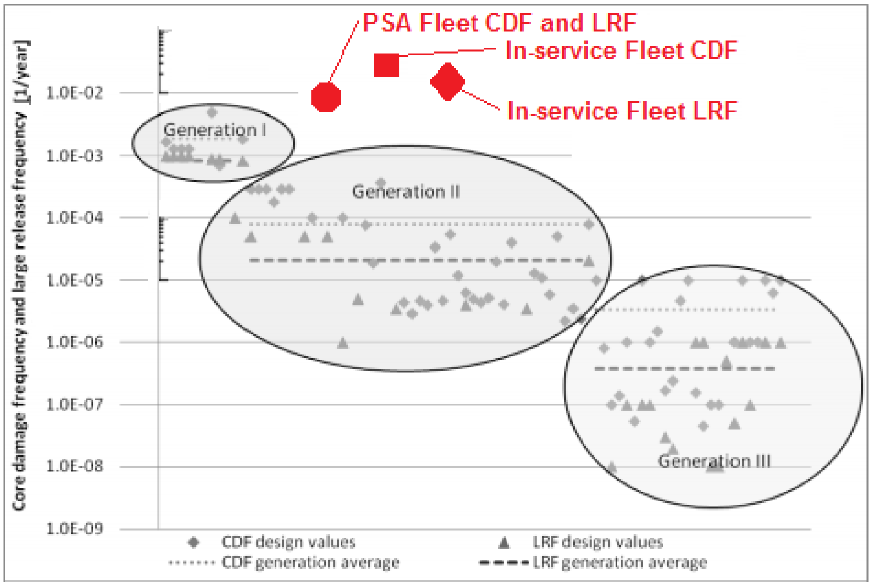

Figure 2: Nuclear Reactor Core Damages (Meltdowns) and Large Radioactive Releases (Adapted from NEA [3])

PSA, REACTOR DESIGN ACCIDENT FREQUENCIES

Overall accident frequencies are expressed in terms of the large release frequency (LRF, sometimes reported as the large early release frequency) and the core damage frequency (CDF), or meltdown frequency. The LRF equals the frequency of large scale radioactive particulate releases, or contamination, to the environment, and the CDF equals the frequency of reactor power plant meltdowns, which include discrete fuel rod melting, graphite channel melting, partial meltdowns, and complete meltdowns.

Reactor CDF's and LRF's are compared in Figure 2 (NEA [3]), using two approximations that result from the age of the data. One approximation occurs since the original plotted values may be larger due to safety modifications implemented after the TMI-2 and Fukushima accidents. The other approximation occurs since the CDF's and LRF's were grouped together when this figure was first conceived, and these quantities are now known to have different average values. These approximations are reasonable given the accuracy of other calculations in this work. Then, from Fig. 2 the average values for the CDF's or LRF's of generation II reactors equal

$$PSA, Reactor\ design\ CDF\ (Average) = 2 \cdot 10^{-5} \quad (2)$$

$$PSA, Reactor\ design\ LRF\ (Average) = 2 \cdot 10^{-5} \quad (3)$$

PSA, REACTOR FLEET ACCIDENT FRQUENCIES

Since reactors operate independently, CDF's and LRF's are statistically independent, which means that the CDF's and LRF's for the reactor fleet do not equal any one of the specific frequencies plotted in Fig.2 for various reactor designs. Probabilistically, the CDF's and LRF's equal the sum of their individual probabilities, such that

$$PSA, Fleet\ CDF\ = 450\ reactors \cdot 2 \cdot 10^{-5} \frac{accidents}{reactor \cdot years} = 9 \cdot 10^{-3} \frac{accidents}{year}$$
$$\rightarrow 111\ years\ until\ the\ next\ meltdown \quad (4)$$

$$PSA, Fleet\ LRF\ = 450\ reactors \cdot 2 \cdot 10^{-5}\frac{accidents}{reactor \cdot years} = 9 \cdot 10^{-3}\frac{accidents}{year}$$
$$\rightarrow 111\ years\ until\ the\ next\ radioactive\ release$$

5

These values are plotted in Fig. 2 as "PSA Fleet CDF and LRF". Note that the PSA fleet frequency significantly exceeds the collection of reactor design values shown in Fig. 2. Using PSA, the expected time between accidents for the reactor fleet is once in 111 years rather than once in 50,000 years for a single reactor. Therein lies an ethical problem - a non-rigorous interpretation of this figure, in the absence of the fleet frequency, can erroneously conclude that nuclear reactors are remarkably safer than they actually are, where statistics can be easily misunderstood.

In fact, an OECD report [4] stated that Fig. 2 proves that the "predicted frequency for a large release of radioactivity from a severe nuclear power plant accident has reduced by a factor of 1600 between the early Generation I reactors and the Generation III/III+ plants being built today." While this statement may be true for a single reactor design, the fleet reduction of severe accidents per year is only reduced by a factor of 3.55 = 1600/450. The OECD statement confused statistics to yield a misrepresentative and misleading statement. Implicit in this observation, average fleet frequencies are assumed to exist where this assumption is implied from the fact that singular, blanket, frequencies are used for individual designs – if assumptions apply to all designs, then that assumption can be applied to the entire fleet.

To be clear, the data from this figure proves that a severe accident in the world-wide reactor fleet is expected approximately once in every one hundred years – not once in every $2\cdot10^{-5}$- years – interpretations are sometimes confused with respect to this graphic depiction of reactor accidents.

IN-SERVICE FLEET FREQUENCIES

Nuclear accident frequency data is further skewed by actual, in-service nuclear accident data. The time between nuclear power plant accidents is plotted in Fig. 3. Data from multiple countries represents all power plant meltdowns due to the melting of single fuel rods, partial cores, or complete cores.

In-service Accident Frequency Calculations for the Reactor Fleet

To address this concern, the time between accidents and frequencies are calculated in Tables 1 and 2 and plotted in Figs. 2 and 3. Accident frequencies were assumed to be random events throughout the fleet, regardless of design. Also, the use of probability calculations for this small sample size is assumed to be valid. That is, if probability principles apply to thousands of interrelated components in a nuclear plant, then those same principles can be applied to small samples– pick and choose is not an option – either probability theory applies or it does not.

Linear accident approximations are reasonable and readily provide standard deviations (σ) from Excel. Two different linear approximations are shown in Fig. 3 – one equation depicts all meltdowns – the other equation depicts meltdowns starting at TMI-2. Note that data after the TMI-2 accident better reflects the performance of the fleet, since major changes followed TMI-2 to improve reactor safety. Furthermore, an assumption is made that these

Calculation results are listed as follows.

1. The mean time to the next power plant meltdown equals 26.91 years ± 16.21 years with 95% confidence, using σ = 6.94 years and a student-T = 2.3534 for the four sample data set - assuming a normal, Gaussian distribution - of TMI-2 Saint-Laurent, Chernobyl, and Fukushima. This data set is reasonable and includes the TMI-2 reactor improvement effects on meltdown probabilities. In short, there is a 1 in 40 probability of a meltdown in 2022, and there is 50% probability that a meltdown will occur before 2038, assuming that additional reactor safety improvements following Fukushima effects are approximated to be proportional to TMI improvement effects. That is, the linear approximation for the actual, Post-TMI-2, meltdowns is extrapolated to the next, future meltdown date. This approximation is a reasonable assumption based on the limited data, such that

   $$y = 7.3581x - 68.74 \text{ (Table 1, Fig. 3)}$$

   6

   where y is the number of years between accidents, and x is the number of accidents.

2. The mean time to the next large release is predicted in 2065, with a 1 in 40 probability of a large release in 2032. This prediction is determined from the fact that one out of two meltdowns results in a large release as discussed above in "Primary Accident Descriptions". Since the LRF is a dependent probability with respect to the CDF,

The LRF in-service fleet frequency = The CDF in-service fleet frequency / 2 = 0.037/2
= 0.018 *large releases/ year* (Table 1, Fig. 2) 7

3. If preventive actions are implemented to prevent explosions due to fluid transients, the mean time to the next large release can be postponed as discussed above in "Primary Accident Descriptions". For the four reactor set/group under consideration, one of two explosions and one of two large releases are caused by fluid transients. By implementing corrective actions to stop fluid transient induced explosions, the mean time to the next large release is predicted in 2118, with a 1 in 40 probability of a large release in 2054, and

The extended LRF in-service frequency = The LRF in-service frequency / 2 = 0.018/2 = 0.009 *large releases / year = Fukushima in-service accident frequency = Chernobyl in-service accident frequency*
= Criticality in-service accident frequency (Table 1, Figs. 2 and 4) 8

4. Chernobyl effects affect the limited data set under consideration, but significant effects of Chernobyl data are primarily limited to the prediction of the next criticality accident. A lack of regulatory control has been used to differentiate between accidents in OECD and non-OECD countries (NEA [3], and this issue has been used to discount Chernobyl effects on accident evaluations. Accordingly, the criticality accident predictions may be much higher than shown. Even so, these effects are primarily limited to criticality accident predictions, since Fukushima data dominates Fig. 3 calculations, where near-term accident predictions and are marginally affected. In fact, meltdown and large release predictions in Fig. 3 increase by 14% when Chernobyl is eliminated from calculations.

Summary of In-Service Fleet Accidents

Graphic displays of severe accident predictions are provided in Figs. 2 and 3 to present the first new findings in this discussion, where technical proof is essential to background these significant discoveries. As shown in Fig. 2, mathematical PSA values are called into question since in-service, or actual, fleet frequencies (Eq. 6 and 7) are higher than the PSA values (Eqs. 4 and 5). In short, the in-service fleet frequencies are known to be fact – these values are experimental rather than mathematical theory.

Probabilistic safety analysis (PSA) data from earlier NEA accident evaluations were improved to yield new findings. Of particular interest, previous PSA model results showed that the next major nuclear accident would be anticipated in 2127 (Eq. 4). However, a study of in-service accidents provides different results, where a 95% confidence interval is used to study nuclear accidents. Probabilities combined with facts show that an accidental meltdown like Three Mile Island may occur by 2022 with a small probability, and a meltdown is likely before 2038. Similarly, the next major radioactive release like Fukushima or Chernobyl is expected to occur between 2032 and 2065. Explosions also cause these major radioactive material releases, and some explosions are caused by nuclear power plant pump operations. These specific explosive blasts of radioactive dust into the air and across the globe can be stopped by controlling pump operations. Actions to stop these explosions can move the predicted radioactive release to dates between 2054 and 2118.

To better understand these predictions, the applied 95% confidence level is typical throughout many industries including nuclear facility instrumentation, and this 95% confidence level was assumed here for calculations, even though a case can be made to use 99% confidence due to the importance of the results. A 99% confidence level shows that an accident and large radioactive release can happen at any time, but the mean time to the next power plant meltdown or radioactive release remains the same (These 99% confidence calculations are not shown, but a student-T value = 4.541 is substituted into all calculations).

Risks are not considered in Fig. 3 since risks would distribute proportionally for this example and yield little additional insight. Also, the effects of lessons learned from Fukushima may affect this meltdown prediction, but cannot be concisely quantified. An implicit assumption is that Fukusima Lessons Learned are as effective as TMI-2 Lessons Learned with respect to reactor safety improvements.

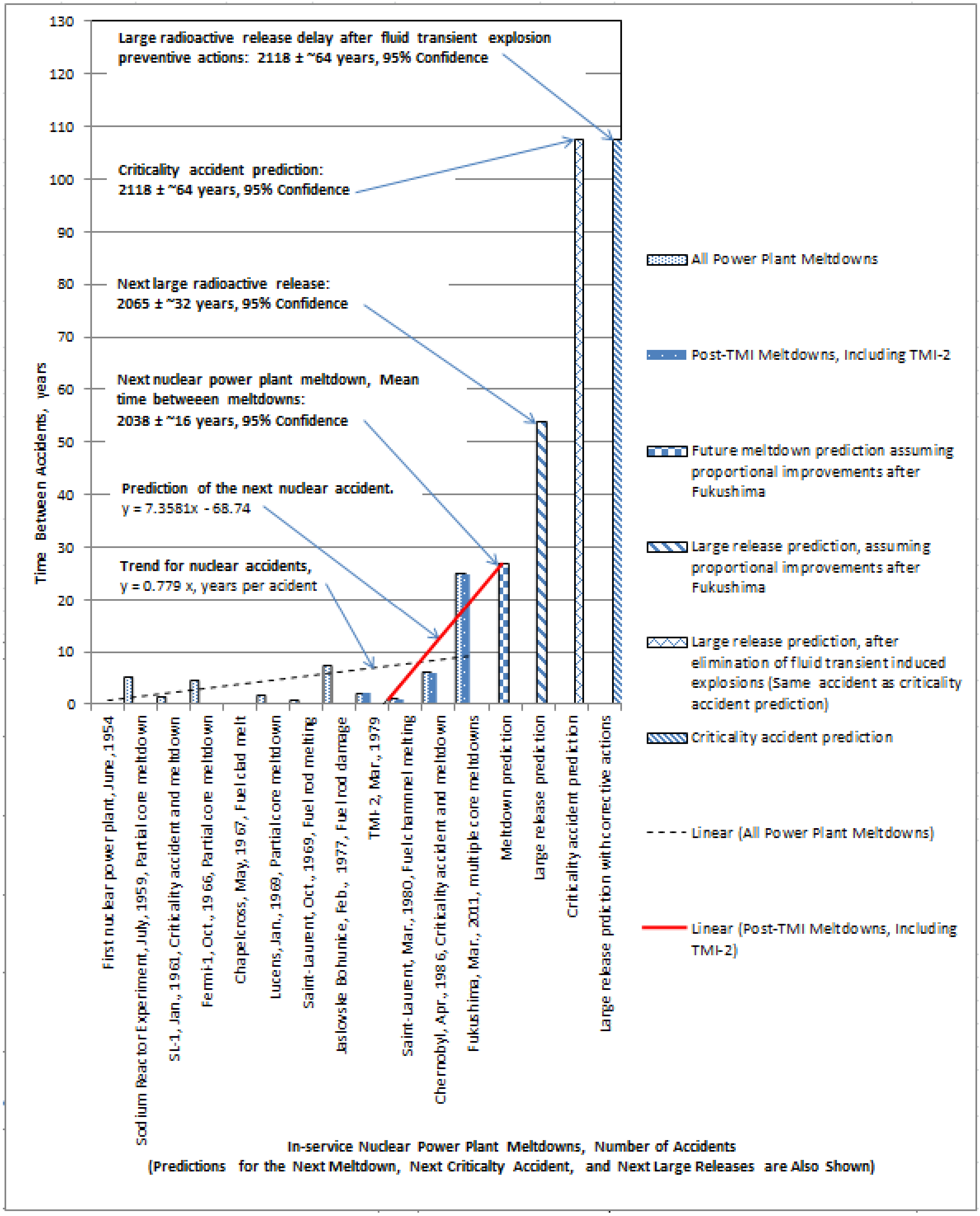

Figure 3: Nuclear Power Plant Accident Evaluations

Table 1: Power Plant Meltdown History, Years Between Accidents

All power plant meltdown accidents	Accident number	All meltdowns, years	Post-TMI meltdowns, including TMI-2, years	Future accident predictions, mean time between accidents, years
First nuclear power plant, June, 1954	0	0	---	---
Sodium Reactor Experiment, July, 1959	1	5.083	---	---
SL-1, Jan., 1961	2	1.50	---	---
Fermi-1, Oct., 1966	3	4.583	---	---
Chapelcross, May, 1967	4	0.583	---	---
Lucens, Jan., 1969	5	1.75	---	---
Saint-Laurent, Oct., 1969	6	0.75	---	---
Jaslovske Bohunice, Feb., 1977	7	7.5	---	---
TMI-2, Mar., 1979	8	2.0833	2.0833	---
Saint-Laurent, Mar., 1980	9	1	1	---
Chernobyl, Apr., 1986	10	6.0833	6.0833	---
Fukushima, Mar., 2011	11	24.916	24.916	---
Meltdown prediction	12	---	---	26.91
Large release prediction	---	---	---	53.83
Criticality accident prediction	---	---	---	107.66
Large release prediction with corrective actions (Same accident as criticality accident prediction)	---	---	---	107.66

Table 2: In-service, Fleet Frequency Probability Calculations

Future meltdown prediction assuming proportional improvements after Fukushima		Large release prediction, assuming proportional improvements after Fukushima		Large release prediction, after elimination of fluid transient induced explosions	
TMI, etc., y = 7.3581x - 68.74, years	26.91	TMI, etc., y = 7.3581x - 68.74	53.83	TMI, etc., y = 7.3581x - 68.74, years	107.66
σ, years	6.94	σ, years	13.89	σ, years	27.55
95% Confidence, years	16.21	95% Confidence, years	32.690	95% Confidence, years	64.85
Student-T	2.3534	Student-T	2.3534	Student-T	2.3534
Next meltdown prediction, year	2038.2	Next meltdown prediction, year	2065.1	Next meltdown prediction, year	2118.9
Near term meltdown prediction, year	2022.0	Near term meltdown prediction	2032.4	Near term meltdown prediction, year	2054.1
Long term meltdown prediction, year	2054.4	Long term meltdown prediction	2097.8	Long term meltdown prediction, year	2183.8
CDF Frequency, meltdowns/year	0.037	LRF Frequency, Large release/year	0.018	LRF Frequency after fluid transient explosion elimination, Large release/year	0.009
Criticality accident frequency	0.009	Criticality accident frequency	0.009	Criticality accident frequency	0.009

In other words, there is a reasonable probability that another Fukushima type accident is expected a century earlier than previous PSA predictions. Again, an ethical problem arises - using in-service accident data and probability theory, the expected time between accidents for the reactor fleet is once in ~27 years rather than once in 111 years for the fleet or once in 50,000 years for a single reactor design. Publicized predictions are remarkably misleading and incorrect, an accident is predicted in the near future, and misleading data provides an incredibly false sense of security and safety.

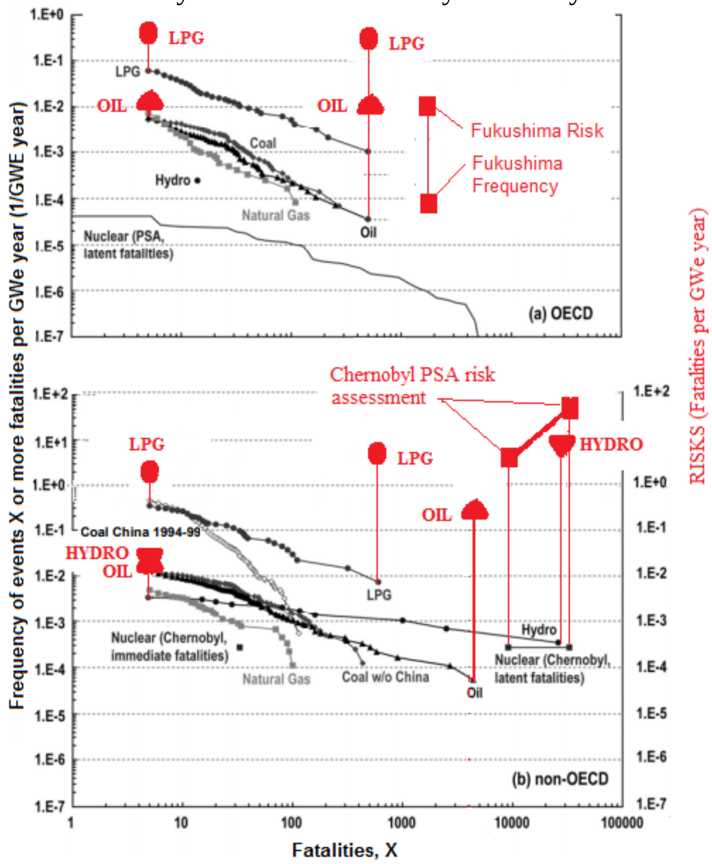

Figure 4: Frequency vs. Consequences and Risk vs. Consequences for Severe Accidents[6] (Deaths ≥ 5) (Note: All data for 1969 – 2000, 31 years, except China coal, 1994-1999, and Fukushima, 1990- 2011, 31 years. Adapted from NEA [3 and 7])

PSA ACCIDENTAL DEATH FREQUENCIES VERSUS RISKS FOR THE ENERGY INDUSTRY

Nuclear Energy Agency (NEA [3]) accident data incorrectly shows that nuclear plants are much safer than other industries. To do so, NEA accident frequency data was used to compare nuclear power plant accidental deaths to other industrial deaths, as shown in Fig. 4. Considering frequencies alone, Chernobyl accidental deaths appear to have less significance than 5 deaths in the oil industry, where the effects of thousands of predicted Chernobyl cancer deaths are excluded from consideration. Equating the Chernobyl accident to a pipeline accident is entirely unacceptable.

Alternatively, the use of PSA risk calculations, instead of frequency calculations, effectively weight cancer deaths caused by accidents, where risks are more appropriate than frequencies to compare accident fatalities. When risks are calculated instead of frequencies, nuclear power risks are comparable to risks associated with other energy industries - a much different conclusion, since reactors are not as safe as

[6] NEA also calculated some risks that differed from risks shown in this figure, but NEA calculated nuclear risks, and risks were comparable to other industrial risks, NEA [3].

previously believed. To reach this conclusion, select risks were calculated for various energy industries, which are either part of the Organization for Economic Cooperation and Development (OECD), or not part of the OECD, which is an organization of 34 democratic member nations.

Calculated using Eq. 1, risks are reported in Fig. 4 to compare nuclear energy accidental death risks to risks associated with other energy industries. Chernobyl cancer risk estimates are provided by NEA in the figure, but cancer risk estimates vary considerably ("Health Effects of the Chernobyl Accident: An Overview", World Health Organization, Geneva, Switzerland, 2011). Cancer risks from TMI-2 are generally considered to be negligible, and resultant accidental death risk equals zero. The cancer death risks associated with Fukushima are widely disputed, but a reputable estimate is available, where a "discernible increase in cancer incidence … attributed to radiation exposure from the accident is not expected, and the evacuations themselves also had repercussions for the people involved, including a number of evacuation-related deaths", but no immediate deaths attributed to the meltdown were reported (UNSCEAR [5]). However, approximately 141 people died due to the evacuation, i.e., mostly elderly people died from the accident, and the increased rate of deaths decreased to pre-accident death rates within the first year after the accident (Yasumuru [6]). In other words, there is an accidental death risk for Fukushima due to evacuation related deaths, shown in Fig. 4, where calculations were performed by using Eq. 1 and Fig. 5 for a 31 year time span (similar to NEA data), such that

$$Fukushima\ Accident\ Frequency/\ GWe \cdot year = 1/12405\ GWe \cdot year = 8.06 \cdot 10^{-5} \tag{9}$$

$$Fukushima\ Accident\ Risk, Fatalities/\ GWe \cdot year = 141/12405\ GWe \cdot year = 1.14 \cdot 10^{-2} \tag{10}$$

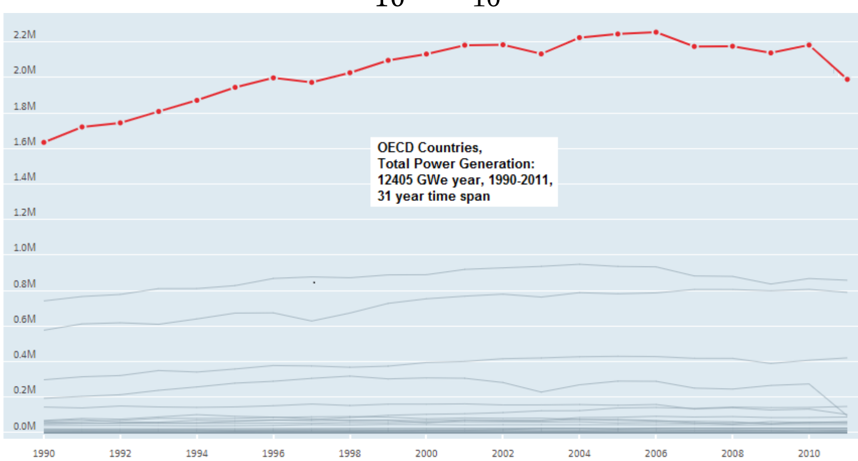

Figure 5: OECD Country Energy Generation, Total Gigawatt Hours for OECD Countries (NEA, [7])

In short, PSA frequency presentations skewed available data to provide results favorable to the nuclear industry, where in-service fleet risks provide less favorable results. That is, accidental nuclear power plant deaths are comparable to the risks of other fuel industries, which is contrary to earlier reports. Even so, approximately 288,000 deaths have been accelerated during a single year due to airborne fossil fuel particulates, according to the NEA. This statistic may lead to a different conclusion that nuclear fuels may be safer than fossil fuels. These observations do not change the conclusion that risks are better suited to compare different types of accidents. All in all, nuclear power plants are not significantly safer than other industries, since explosive, radioactive releases may cause thousands of cancer deaths.

And again a question of ethics arises - previously published PSA values skewed the data presentation to incorrectly publicize and overstate reactor safety. In other words, risks show that existing data prove that nuclear plants are no safer than other industries, but nuclear industries have comparable safety to those industries.

COMPARISON OF NUCLEAR POWER PLANT ACCIDENTS TO OTHER RISKS

Additionally, Fig. 6 presents a previous understanding of reactor risks that now changes slightly due to technology advances. In this figure, "unknown risks are defined at the high end by hazards judged to be unobservable, unknown, new, and delayed in their manifestation of harm", where the effects were unknown at the time that this figure was first created (Slovic, 1987 [8]). "Dread risks are defined at the high (right-hand) end by perceived lack of control, dread, catastrophic circumstances, and the inequitable distribution of risks, where nuclear weapons and nuclear power score highest on the factors that make up this factor." Figure 6 is modified to reflect this new understanding of cancer risks.

In Fig. 7, most frequency and risk calculations from above are presented to provide an overall graphic summary of calculation results and conclusions. Note that Fig. 7 shows that reactors have higher risks than airline travel and explosions, which in turn revises Fig. 6 accordingly. Also, NRC regulatory reactor design requirements are depicted. And again a question of ethics arises - theoretical frequencies have implied that nuclear reactors are much safer than they are. Another observation is that reactor design DF's and LRF's are dependent, and as such the LRF and CDF differ by a factor of 2 yet NRC regulations require that these two values must differ by a factor of 10 – this issue needs to be resolved (Leishear [2]).

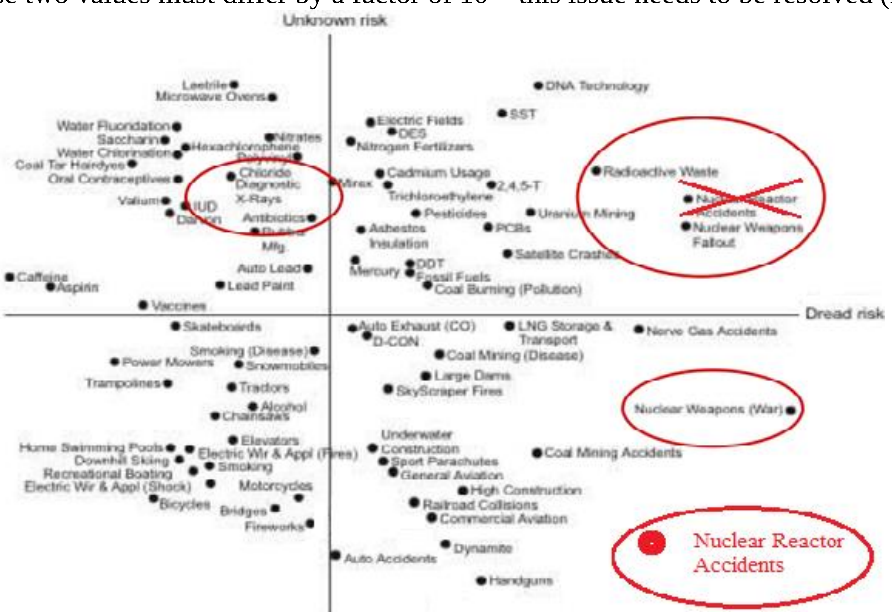

Figure 6: Comparison of Nuclear Power Plant Risks to Other Risks (Adapted from Slovic, [8], Permission request in process**)**

AN ETHICAL DILEMMA IN THE NUCLEAR INDUSTRY

These findings constitute new safety risks. Risks throughout the oil, gas, coal, and hydro industries are widely accepted due to the common energy benefits provided by these industries, and perhaps the same acceptance may apply to this new risk for the nuclear industry. Whether or not these new risks are acceptable is outside the scope of this publication, but the prevention of explosions will drastically reduce future risks.

All in all, there are many new questions that relate to nuclear power plant safety, where previous graphic descriptions used to demonstrate nuclear industry safety are incorrect due to the Fukushima explosion that sharply changed the understanding of reactor safety. Additionally, publicized, misleading nuclear data challenges the principles of ethics. Harm from nuclear energy has been misrepresented, which curtails the freedom for citizens to make informed decisions about nuclear power plant safety.

CONCLUSIONS

Significant claims about nuclear power plant safety are established here, and the arguments to do so are logically sound and backed by facts. Probability and statistics are widely used to assess nuclear plant operations and safety, and probability and statistics along with factual nuclear accident data are used here to prove several primary discoveries,

1. Previous publications are grossly inadequate, in that skewed data led people to believe that nuclear reactors were remarkably safe, when they are not.
2. There is an imminent risk of another nuclear accident.
3. Frequency estimates for nuclear reactor accidents were previously estimated at once in 50,000 years, but the TMI-2, Chernobyl, and Fukushima accidents lead to a frequency prediction for a nuclear reactor meltdown of once every 27 years - a remarkable difference.
4. Every other meltdown accident – every 54 years is expected to result in a large radioactive release, similar to Chernobyl of Fukushima.
5. Accidental death risks are roughly equivalent to other industrial, man-made, and natural event death risks, contrary to previous publications.
6. The risks of future accidents can be minimized if explosion prevention is incorporated into nuclear power plant operations.

Since these risks have not been addressed in other studies, government publications, or regulatory publications, the danger of another nuclear reactor accident is high. One may claim that safety analysis prevents nuclear accidents, but a safety analysis did not prevent Fukushima. One may claim that explosions like Fukushima or Chernobyl cannot happen again since much has been learned, but only recently a discovery was made that TMI-2 experienced an explosion rather than a fire, and Fukushima reports do not yet acknowledge the autoignition cause of explosions. Until and unless these risks are acknowledged and addressed, the risks are not likely to be resolved, and the probability of a near-term nuclear accident will continue.

A primary ethical question for this author was whether or not to publish these major new discoveries that challenge nuclear industry experts. Ethically, how can I not publish the facts that I know to be true when lives are at stake?

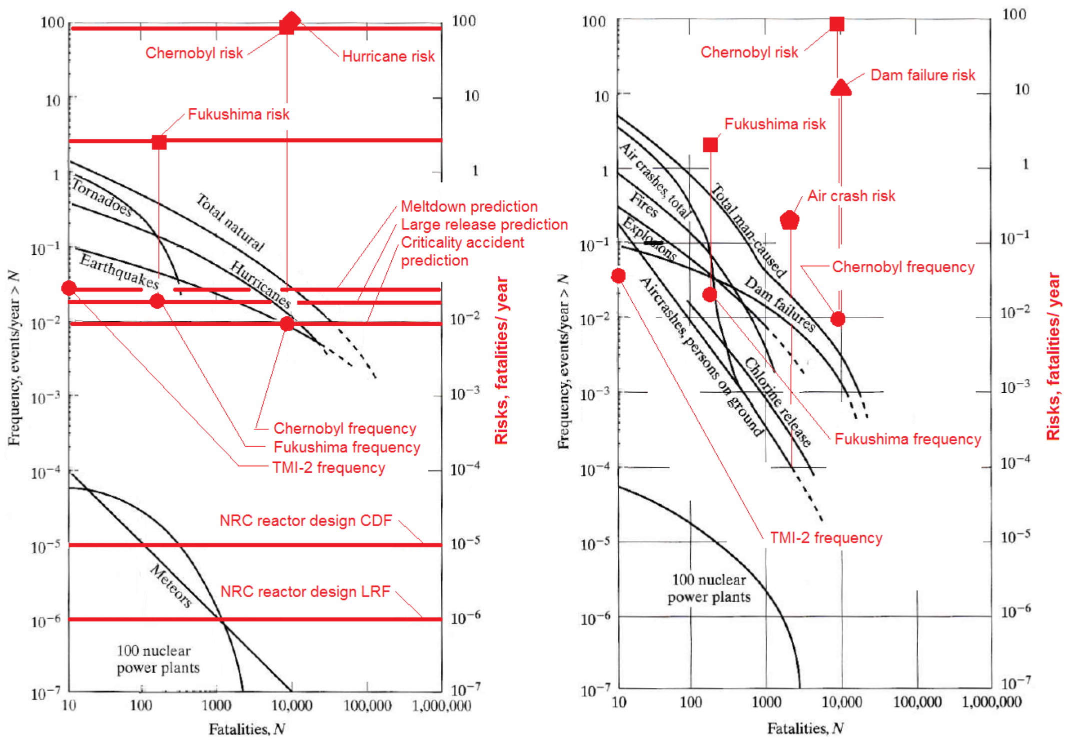

Figure 7: Comparison of Power Plant Accidental Deaths (≥5) to Natural and Man-Made Events
(Adapted from NRC [9])

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APPENDIX C: THE FLUID TRANSIENT DISASTER

THE FLUID TRANSIENT DISASTER

Robert A. Leishear, Ph.D., P.E., ASME Fellow

Burnt into the headlines of our lives, fluid transients throughout industry kill people and destroy property and the environment, i.e., transients autoignite fire balls and explosions in nuclear power plants, transients burn people to death in gas pipeline explosions, transients destroy pipe systems and cause oil spills, and transients break 250,000 U.S water mains per year. Of urgent importance, fluid transients ignited the Fukushima explosions, and the next nuclear accident is predicted to occur before 2038. All of these explosions are not accidents at all – they are preventable.

Two theories interrelate all of these tragedies – the Leishear Stress Theory and the Leishear Explosion Theory. The Leishear Explosion Theory proved that water hammer stresses are multiplied by a dynamic load factor (DLF) – as high as four – and DLFs magnify the effect of water hammers. For example a valve slam can cause 300 psi pressures or much greater, and the effect of a 300 psi pressure can be equivalent to a nearly 1200 psi pressure. The Leishear Explosion Theory explains how fluid transients compress flammable gases to their autoignition temperature to explode those gases - similar to autoignition in a diesel engine. That is, the compression of explosive gases heat, autoignite, and explode those gases.

Fluid transients carve a path of death and destruction. Prior to the invention of these theories, this disaster was out of control with no means to stop it. In the wake of the invention of these new theories, the means to stop these evolving disasters are here - the future can be changed – death and destruction need not be accepted as incidental to industrial operations.

INTRODUCTION: INVENTING NEW THEORIES TO CURTAIL THE DISASTER

This paper provides a summary and updates of many years of research, and many peer reviewed publications, to explain the interrelationships between pipe failures and explosions. By combining 46 publications, a new outlook on this overwhelming problem is presented here. Explosions can be stopped, and pipeline ruptures and leaks can be stopped.

This research started with the Leishear Stress Theory that was the focus of Dr. Leishear's University of South Carolina (USC) Ph.D. in Mechanical Engineering (Leishear) and an American Society of Mechanical Engineers (ASME) textbook (Leishear). Numerous publications followed that research as Dr. Leishear comprehensively explained the physics of water hammer destruction in liquid filled systems, where the most recent publication focused on stopping pipeline damages (Leishear). During transients, nearly sonic pressure waves are caused by operating valves and pumps, which travel along the bore of pipes, and break piping systems typically due to fatigue cracking but occasionally due to sudden one-time overload failures. These pressure transients affect any industry, where specific examples are water main breaks and oil pipeline spills.

Dr. Leishear's full time voluntary USC Nuclear Engineering Ph.D. research during the past three and a half years, builds on that theory to explain nuclear power plant explosions, off-shore oil rig explosions, and gas pipeline explosions. These explosions share a common cause – fluid transients caused by pump, compressor, or valve operations compress flammable gases to autoignition and explosion. Smaller explosions crack pipelines in nuclear power plants, and resultant fatigue cracks occur in piping. Larger explosions include gas pipeline explosions that blast out bomb-like craters, and shoot tons of dirt into the air along with pipe sections weighing more than a ton that land more than 100 feet away from the blast site – several fatalities occur every year during gas pipeline explosions. Even larger explosions occurred at Three Mile Island and Fukushima, where the Fukushima explosion killed nearly 141 people during relocations, after the blast shot radioactively contaminated dust into the air that circled the globe and forced the evacuation of 196,000 local residents – 96,000 were still relocated as of 2016, according to the

Chief Engineer at Fukushima. Numerous publications document this explosions research, where are summarized in the most recent publications (Leishear). Continuing Ph.D. research progresses to understand explosions and preventive actions to stop explosions, but publishing the present status of research encourages others to work in this field of research.

Figure 1: A Water Main Break Caused by Repeated Water Hammers
(https://www.youtube.com/watch?v=vp2G6hqRh1Q)

Water Main Breaks

An estimated trillion dollars in water main breaks are expected in the U.S. in the next 25 years – presently 13 billion dollars per year - which can be prevented. Water hammers, or fluid transients in liquid filled systems, break nearly all of these water mains, regardless of the material used to fabricate them, e.g., plastic, concrete, steel, or cast iron. Examples of water main breaks pepper the press and television, as shown in Fig.1. Most of these breaks are cracks and the rest of these breaks are caused by corrosion, which in turn is caused by water hammer. That is, water hammer initiates cracks to initiate crevice corrosion in those cracks by providing a new and constant water source into the cracks. Water then leaks from the mains to burrow a path up through the soil to seep or sometimes erupt through roadways. The difference between the occurrence of seepage and geysering depends on the amount of pressure and the size of the cavern below the roadway at the time. If sufficient soil has been moved to apply pressure to the underside of the roadway, the roadway can violently rupture. Closing fire hydrants and valves slower, and starting pumps slower, will stop water main breaks (Leishear). For this change to be effective, water supply operators, fire fighters, and others who work with water systems need to be informed that they need to operate fire hydrants and valves slower in a matter of minutes rather than seconds as currently practiced.

Water main breaks also present a serious public health risk. When water systems are shut down for major water hammer repairs, bacteria can migrate through other cracks that have not yet been detected. In particular, E.coli is known to reside in soil, and when systems are depressurized, and water is in the soil, E.coli can migrate into the drinking water supply.

Piping Cracks

Additionally, fatigue cracks caused by water hammer destroy piping systems throughout industry. For example 200 piping failures were misdiagnosed as corrosion failures at Savannah River Site for more than 40 years (Leishear). The Leishear Stress Theory was first invented to solve this specific problem, water hammer was stopped, and piping failures stopped 17 years ago in 2002. Also note that piping cracks are usually preceded by valve packing leaks as the system is hammered. Again slower valve and pump operations will stop piping damages.

Figure 2: The Gulf Oil Spill, Caused by a Fluid Transient Explosion
(https://cdn.cnn.com/cnnnext/dam/assets/120424051724-bp-oil-spill-horizon-horizontal-large-gallery.jpg)

Off-shore Oil Rig Explosions

Off-shore oil rig explosions damage the environment and killed workers. More than 50 explosions have occurred around the globe, where the Gulf Oil Spill is shown in Fig. 2 (*Explosions: A Fresh Look at Chernobyl, Three Mile Island, the Gulf Oil Spill, and Fukushima Daiichi*, R. A. Leishear, 2013, Mensa World Journal). A common refrain of the oil rig workers is, "Swish, run, boom". An explosion occurs in the pipeline due to compression of flammable gases, which is mixed with the oil from the well. This explosion causes a "swoosh" as the oil in the pipeline expands due to the explosion, and oil and fire rush to the oil rig at the surface. "Run" is what the operators do to protect themselves when they hear the "swoosh" sound. Then the boom occurs when the explosive gases reach the oil rig and ignite the oil. Although the cause has been published, there are no present actions to investigate preventive actions.

Figure 3: The 2010 San Bruno Gas Pipeline Explosion, Caused by System Pressure Changes, Killed 8 People

Oil Pipeline Spills

Also, fluid transients cause oil pipeline spills across the U.S. in oil distribution pipelines, where oil pipelines break due to the repeated closing of slam valves that generate fluid transients. Similar to water main breaks, these fluid transients result in fatigue failures, which are similar to bending a coat hanger back and forth. Slam valves are used for flow control throughout the oil industry, and closing them slower will stop the pipeline breaks and resultant oil spills.

Figure 4: Typical Gas Pipeline Explosions Caused by Fluid Transients

Gas Pipeline Explosions

Natural gas distribution pipelines crisscross the country, and numerous explosions occur every year, sometimes creating 60 to 80 feet long craters. The use of slam valves and compressor operations heat flammable gases to autoignition and explosion. Every year five to ten accidents are serious enough to result in severe injuries or death (See Fig. 3). Control of pipeline transients can stop these deaths (*The Primary Cause of Oil and Gas Pipeline Spills and Explosions*, 2019, R. A. Leishear, Empowering Pump and Equipment, eMAgazine). This conclusion was reached through a survey of U.S. gas pipeline explosions.

Accident photos consistently prove that pipes explode from the inside to the outside. Accordingly, combustion and explosion can only occur if air is inside the pipe - otherwise natural methane gas cannot ignite. Once the assumption is accepted that air is inside the pipelines from maintenance activities or other causes, an explanation of explosions is possible. Air will accumulate at system low points, since air is lighter than methane – note that fluid transient explosions in butane or propane plants will occur at system high points since air is heavier than these gases. The Leishear Explosion Theory then comes into play to explain the explosion cause. Pressure changes in pipelines compress flammable gases to autoignition and explosion. For example, pressure changes were in process when the San Bruno explosion killed eight people, as shown in Fig. 4.

Nuclear Power Plant Explosions

In nuclear power plants, the explosions are limited to the piping in some cases, and in other cases the explosions expand to destroy buildings, cost lives, and damage the environment. This explosion theory resulted in major findings.

Explosions at Fukushima Daiichi occurred at the same time that water was being added to cool in-process nuclear reactor meltdowns – pumps were started and buildings exploded, as shown in Fig. 5. These meltdowns were caused by a forty foot wave from a tsunami that eliminated all power and cooling to the reactors. Different types of explosions occur during meltdowns and recovery. One type of explosion occurs when water is added and some of the water converts to hydrogen and oxygen at high temperature, which is then autoignited by the molten fuel. Prior to, or nearly coincident to, this explosion, large volumes of hydrogen are formed from the corrosion of fuel rod components, where fuel rods generate energy. This fuel rod hydrogen was released to reactor buildings. When mixed with air, an explosion is waiting to happen –all that is needed is a spark source. Fluid transients provide that spark source.

Figure 5: Nuclear Power Explosions Caused by Pump Startups, Fukushima

Figure 6: The Chernobyl Explosion Caused by an Uncontrolled Nuclear Criticality

At Chernobyl, two explosions were separated by seconds (See Fig. 6). The first explosion was primarily due to the sudden creation of hydrogen and air from steam, and the second explosion was due to the rapid release of fuel rod hydrogen to mix with air to explode on contact with the molten fuel. The explosions at Chernobyl were different than most other meltdown explosions since an uncontrolled criticality occurred, and this research determined those differences. This criticality increased the power of the reactor by a factor of at least 100, which in turn, provided more energy to change steam to hydrogen to increase the magnitude of the first reactor explosion. Since there was inadequate oxygen to burn the fuel rod hydrogen inside the reactor vessel, the second explosion occurred when the reactor vessel exploded and the unburnt hydrogen mixed with air. Fluid transient occurred during Chernobyl but were not ignition causes. Chernobyl was investigated to understand the similarities and differences between nuclear meltdowns. Approximately 50 prompt deaths have been attributed to this accident, and more than 9000 cancer deaths have been predicted for this accident.

At Three Mile Island and Fukushima, smaller initial explosions occurred when water was added to the reactor. Larger explosions occurred since hydrogen from fuel corrosion had been added to the reactor containment buildings during meltdowns. Later, as coolant water was pumped into the system, hydrogen was compressed in the reactor pipes, the gas heated, and when exhausted to the reactor buildings hydrogen mixed with air autoignited in the containment buildings. At Three Mile Island, the explosion was contained within a concrete reactor containment building. At Fukushima, buildings of weaker construction were exploded into the air along with a cloud of radioactive dust. The death toll due to Fukushima evacuees was 141, and no deaths have been attributed to Three Mile Island. Some of the details of these two meltdown accidents differed, but the fundamental explosion causes were the same in both Three Mile Island and Fukushima. Two actions can prevent similar explosions.

1) Slow down flow rates for initial water additions.
2) While the system is being refilled to cool the meltdown, vent valves should be left open to prevent gas in the piping from being heated by compression. When the system is filled, the valve used for venting can be closed. Additional research is required to understand the intricacies of this approach.

This new discovery also illuminated the Three Mile Island explosion. The Three Mile Island explosion has been incorrectly reported to be a fire for the past forty years (*The TMI-2 Explosion,* R. A. Leishear, American Nuclear Society, Nuclear News Magazine– in process). A recent publication describes the complex physics of these explosions (*The Autoignition of Nuclear Reactor Power Plant Explosions*, R. A. Leishear, ASME, Journal of Nuclear Engineering and Radiation Science – in publication).

This research has evolved over the years to better understand explosions. In fact, this author followed the opinions of others in an earlier paper (*From Water Hammer to Ignition, the Spark that Ignited Three Mile Island Burst From a Safety Valve,* by R.A. Leishear, 2013, ASME Mechanical Engineering Magazine). With one exception, that article is correct – a fire rather than an explosion occurred. Careful studies of the Three Mile Island meltdown, the Chernobyl meltdown, and the Fukushima meltdowns yielded a conclusion that there must have been an explosion at Three Mile Island following the meltdown. Additional in depth research proved that there was, in fact, a recorded pressure spike that proved that there was an explosion – proof positive of an explosion rather than a fire.

Prevention of nuclear power plant explosions is emphasized by another new finding. The next nuclear power plant meltdown is expected to occur before 2038 with a one in two probability of a large radioactive release at the same time. This finding is important since earlier predictions estimated a meltdown occurrence of 1 in 50,000 years (*Nuclear Reactors Are Not So Safe, A Question of Ethics,* R. A. Leishear, 2019, ASME, Journal of Nuclear Engineering and Radiation Science – in review).

To reach this conclusion, probability theory was applied to the numerous nuclear meltdowns that have occurred. Probability theory has been used to demonstrate that there is a mathematical probability of one nuclear accident in 50,000 years, based on many probability calculations for operating nuclear power plants. Accordingly, the U.S. NRC presently requires a probability to be used during the design of nuclear reactors. This probability is one accident in 100,000 years (*Pump Startups Ignite Nuclear Power Plants, History, Law and Risk*, 2018, R. A. Leishear, British Hydraulic Research Group). Both of these accident probabilities are based on an assumption that each reactor in the world-wide reactor fleet can be considered to be equivalent. Assuming that this assumption is valid, the numerous meltdown accidents that have occurred can be mathematically treated the same way. By doing so, the next meltdown is predicted to occur before 2038, as demonstrated in Fig. 7. To summarize this mathematical conclusion in simplified terms, there have been ten nuclear power plant meltdowns since the 1950's, and an accident rate like this cannot possibly meet a probability of 1 in 50,000 years. Even so, this conclusion considered fact that numerous corrective actions followed Three Mile Island - only accidents after Three Mile Island were used to predict the next meltdown and a one in two probability of a large radioactive release at the same time.

Figure 8: A Nuclear Power Plant Pipe Explosion Caused by Fluid Transients, Brunsbuttel

Smaller Nuclear Plant Piping Explosions

These theories combine to explain piping cracks in nuclear power plants. Hundreds of small explosions occur in nuclear power plants during routine operations. These small explosions - incorrectly diagnosed for decades - sometimes burst pipes like paper firecrackers, and sometimes crack pipes through fatigue, caused by smaller, repeated, cyclic explosions. For example, calculations prove that a pipe explosion at Hamaoka was caused by valve operations, and an explosion at Brunsbuttel was known to have an associated check valve slam (See Fig. 8). The Leishear Explosion Theory was not used for these initial accident evaluations.

During routine operations, gas accumulation events have been known since the 1950's. Prior to this research, these events were thought to be caused by water hammer, but further investigation proved that water hammers cause explosions that cause much higher pressures. Due to normal reactor processes hydrogen and oxygen are formed, and these gases collect at high points in reactors, where these gas pockets can be exploded by pump operations. There is a potential for explosion any time gas collects at high points, and a reactor is depressurized, and the reactor coolant pump is then restarted. In other words, and explosion can happen following routine reactor maintenance for the fleet of 448 world-wide nuclear power plants every time they restart after every 12 - 24 month shut-down intervals.

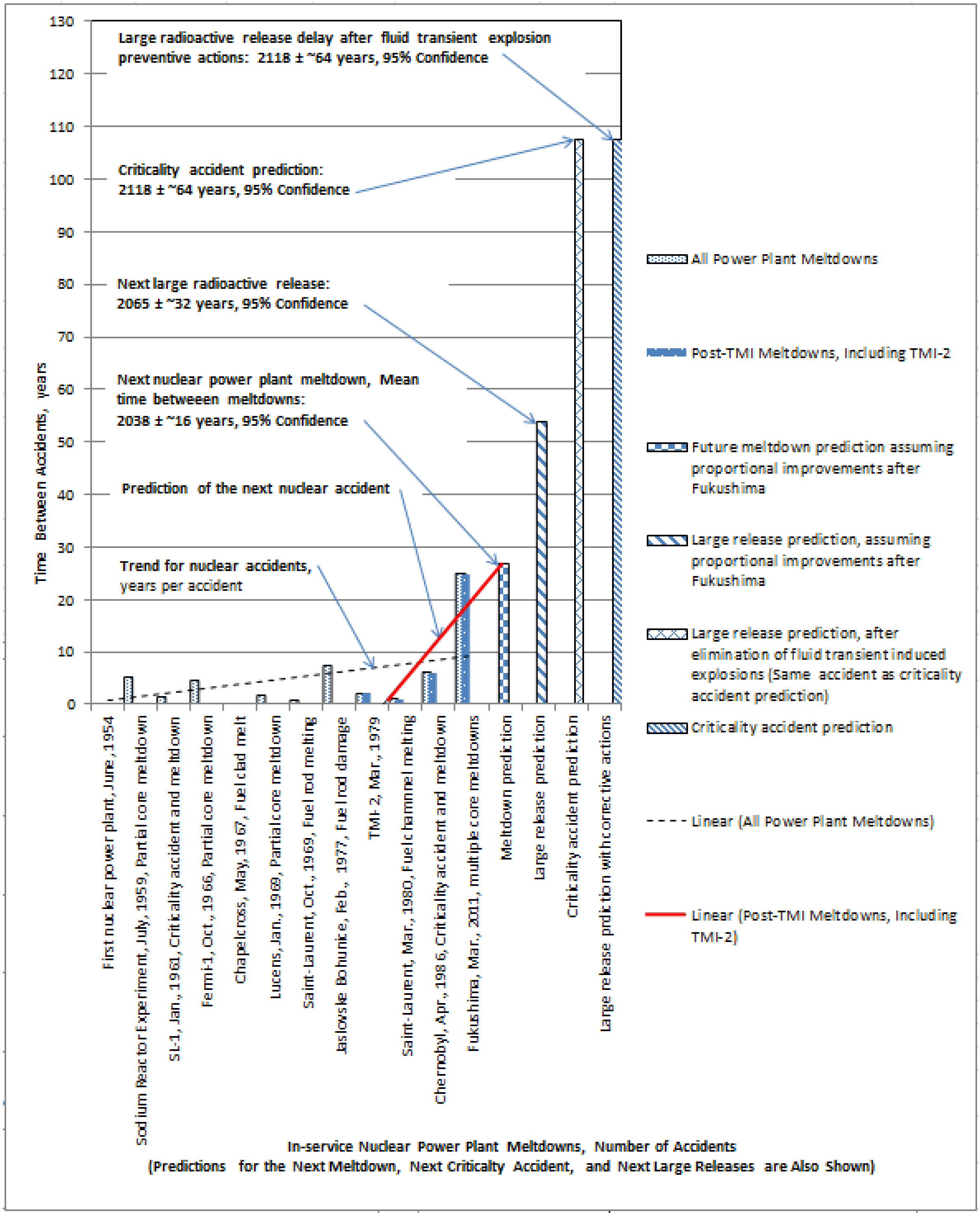

Figure 7: A Nuclear Accident Summary for Power Plants

Stop the Disaster

This multi-pronged disaster can be stopped, where ongoing research investigates preventive actions. The problems are clearly defined, and, in general, slowing down pump and valve operations will prevent pipeline breaks, and venting flammable gases from piping systems will prevent most explosions. The solutions are here, but the specifics questions remain, e.g., how slow should valves be closed, and how slow should pumps be started. Even so, a resolution to off-shore oil explosions has yet to be determined.

Research to date can be summarized as follows.

1. The next nuclear accident is expected before 2038 with a one in two probability of a large-scale radioactive release like Fukushima, and radioactive releases to the air can be prevented to stop indirect deaths, evacuations, and damage to the environment.
2. Gas pipeline accidents kill or severely injure several people every year, and explosions can be stopped.
3. Petroleum industry piping failures cost 7 billion dollars a year, and pipeline breaks can be stopped.
4. Water main breaks cost 13 billion dollars a year and an estimated trillion dollars in damages in the next 25 years are expected. Water main breaks can be stopped.

Publications, DE-FOA-0001817, Advanced Reactor Development Projects: The Autoignition of Nuclear Power Plant Explosions, ARD-20-21608

Robert A. Leishear, PhD., P.E.

Several hundred references support the following publications.

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[2] Leishear, R. A., 2013, Explosions: A Fresh Look at Chernobyl, Three Mile Island, the Gulf Oil Spill, and Fukushima Daiichi, Mensa World Journal, Mensa International Limited, Caythorpe, U.K., 1 p.
[3] Leishear, R. A., 2013, "Pipeline Explosions, A New Theory, ASME Mechanical Engineering Magazine, American Society of Mechanical Engineers, N.Y., N.Y., p. 8.
[4] Leishear, R. A., 2013, A Hydrogen Ignition Mechanism in Nuclear Facility Pipe Systems, ASME Journal of Pressure Vessel Technology, American Society of Mechanical Engineers, N.Y., N.Y., pp. 1-5.
[5] Leishear, R. A., 2013, From Water Hammer to Ignition, The Spark That Ignited Three Mile Island Burst from a Safety Valve, Mechanical Engineering Magazine, ASME, N.Y., N.Y., pp. 46-49.
[6] Leishear, R. A., 2017, "Nuclear Power Plant Fires and Explosions, I, Plant Design and Hydrogen Ignition", Pressure Vessels and Piping Conference, ASME, N.Y., N.Y., 9 pps.
[7] Leishear, R. A., 2017, "Nuclear Power Plant Fires and Explosions, II, Hydrogen Ignition Overview", Pressure Vessels and Piping Conference, American Society of Mechanical Engineers, N.Y., N.Y., 11 pps.
[8] Leishear, R. A., 2017, "Nuclear Power Plant Fires and Explosions, III, Hamaoka Piping Explosion", Pressure Vessels and Piping Conference, American Society of Mechanical Engineers, N.Y., N.Y., 9 pps.
[9] Leishear, R. A., 2017, "Nuclear Power Plant Fires and Explosions, IV, Water Hammer Ignition Mechanisms", Pressure Vessels and Piping Conference, ASME, N.Y., N.Y., 7 pps.
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[11] Leishear, R., 2019, "The TMI-2 Explosion", ANS Nuclear News Magazine, LeGrange Park, Il., 1 p.
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[14] Henrie, J.O., and. Postma, A.K., 1983, "GEND-INF-023, Analysis of the Three Mile Island Unit 2 Hydrogen Burn," The Electric Power Research Institute, 20 pp.
[15] Leishear, R. A., 2019, "Nuclear Power Plants are Not So Safe: A Question of Ethics", Journal of Radiation Science and Technology, ASME, N.Y., N.Y. 11 pps.(in process).
[16] Leishear, R. A., 2018, "Pump Startups Ignite Nuclear Power Plants, History, Law and Risks", British Hydraulic Research Group, Cranfield, Bedfordshire, United Kingdom, 16 pps.
[17] Leishear, 2015, PRE-GI-015, Hydrogen Fires and Explosions in Nuclear Reactors, ML15245A508, US Nuclear Regulatory Commission, Washington, D.C., 12 pps.
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[19] Leishear, 2013, *Fluid Mechanics, Water Hammer, Dynamic Stresses, and Piping Design*, ASME Press, American Society of Mechanical Engineers, N.Y., N.Y., 448 pps.
[20] Leishear, 2015, *Supplement to Fluid Mechanics, Water Hammer, Dynamic Stresses, and Piping Design*, ASME Press, American Society of Mechanical Engineers, N.Y., N.Y, 118 pps.
[21] Leishear, 2019, "Water Hammer Causes Water Main Breaks", Journal of Pressure Vessel Technology, American Society of Mechanical Engineers, N.Y., N.Y. 22 pps. (in publication).
[22] Leishear,, "Grit Blasting for Coatings Accelerates Piping and Structural Failures", Empowering Pumps and Equipment eMagazine, Tuscaloosa, Al., 2 pps.
[23] Leishear, 2019, "The Primary Cause of Oil and Gas Pipeline Explosions", Empowering Pumps and Equipment eMagazine, Tuscaloosa, Al., 2 pps.

[24] Mass Transfer Coefficients for a Non-Newtonian Fluid and Water With and Without Anti-foam Agents", 2010, Leishear, Restivo, Sherwood, Guerrero, ASME, J Fluids Eng- Trans ASME, 21 pps.
[25] Leishear, R. A., Lee, S. Y., Poirier, M. R., Fowley, M. D., and Steeper, T. J. , 2012, "*Comparison of Experiments to CFD Models for Mixing Using Dual Opposing Jets in Tanks With and Without Internal Obstructions*", J Fluids Eng- Trans ASME, 21 pps.
[26] Leishear, Lee, Stefanko, Fowley, Poirier, Steeper, Ervin,Van Pelt, Harp, Giddings, 2013, "*CFD and Safety Factors*", ASME, Mechanical Engineering Magazine, pp. 44-47.
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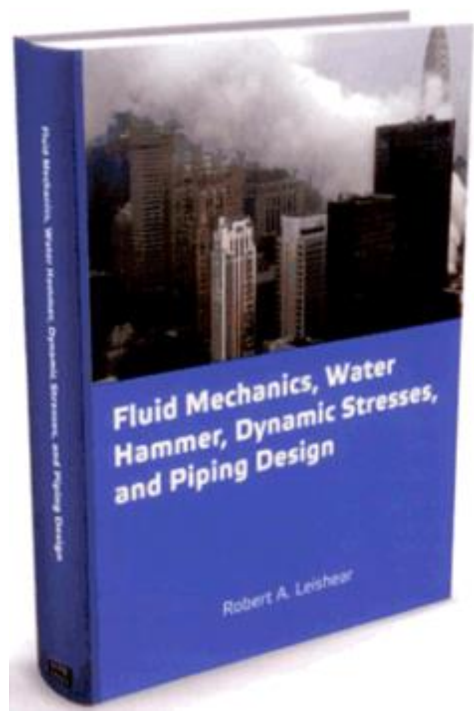
Leishear Engineering LLC

U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

THE AUTOIGNITION OF NUCLEAR POWER PLANT EXPLOSIONS

Robert A. Leishear, Ph.D., P.E.
ASME Fellow, NACE Senior Internal Corrosion Technologist, Journeyman Sheet Metal Mechanic
Leishear Engineering, LLC

Brunsbuttel Nuclear Power Plant Explosion



Required Background Research

Submitted to the DOE, Office of Nuclear Energy, 10/30/2019.

Capabilities, DE-FOA-0001817, Advanced Reactor Development Projects: The Autoignition of Nuclear Power Plant Explosions, ARD-20-21608

Applicant, Principal Investigator: Robert A. Leishear, Ph.D. P.E., ASME Fellow, Leishear Engineering, LLC, Email - Leishear @aol.com, Website – leishearengineeringllc.com, 803-641-6753

CAPABILITIES

Although not part of infrastructure capabilities, the primary resource for this project is Dr. Leishear's dedication, which is reflected by his extensive education and volunteer research that is documented in the Past Performance File. All in all, the primary resource for this proposal is an extreme personal dedication to stop nuclear power plant explosions and prevent potential loss of life.

INFRASTUCTURE

Infrastructure consists of the following.

1. A four core, high memory processor for engineering computing located at LELLC is available for full time use to model nuclear reactor operations, using Relap5, Polaris, AFT Impulse, Parcs, Frapcon, Fraptran, Matlab, Keno, and Origen. This $6000 processor was purchased for the sole purpose of performing this research. Budget has been provided for a another computer in the case of computer failure.
2. AFT Impulse and Fluent will be purchased as part of this contract. LELLC already possesses the other Codes.
3. Fluent models are planned be modeled on this LELLC processor.
4. Access is available to a 20 core processor at the University of South Carolina, Nuclear Engineering Department. Larger Fluent models could be performed at this facility for schedule acceleration. However, budgets have not been allocated for a 20 core license to utilize this capability. Accordingly, modeling is planned on a four core computer for all research, and excessive programming times will be compensated by rescheduling other activities while programs are running. If required a budgeted second computer will be purchased so that two computers can perform parallel models to reduce schedule risk.
5. The SimuTech Group has capabilities for consulting / training Dr. Leishear, and they are located in six different cites, and they have more than 100 staff members to provide the required consulting to ensure project success and timely training.

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Website – leishearengineeringllc.com
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803-641-6753

EXPERIENCE

Leishear Engineering, LLC, S.C., 2016-2018, ***Consulting Engineer –Research, Design, and Failure Analysis*** – Systems: *Fluid Systems, Structures, Piping, Pumps, Compressors, Fans, and Machinery.* Expertise: *Failure Analysis, Water Hammer, Fluid Flow, Structural Analysis, Failure Analysis, Vibrations, Instrumentation, Explosions, Nuclear Engineering, Safety Analysis, Mixing, Thermodynamics, and Heat Transfer.*

Savannah River Nuclear Solutions, S.C., 2014-2016, ***Fellow Engineer – SRS Piping Design Authority.***
Savannah River National Laboratory (SRNL), S.C., 2007-2014, ***Fellow Engineer, Project Manager.*** (4 SRNL Awards); *Research Engineer – Fluids, Mass Transfer, and Robotics; Radioactive Packaging Engineer; Calibrations (Metrology) Engineer; Safety Analysis Engineer, Quality Assurance Engineer.*

Savannah River Remediation (SRR), LLC, S.C., 1991-2007, ***Fellow Engineer, Principal Researcher, SRS Pump Design Authority,*** (1 SRR President's Award and 10 SRR Vice President's Awards, $50,000,000 cost savings) - ***Shift Technical Engineer,*** *Design Engineer, Contract writer, Plant Engineer, Test Engineer, Vibration Engineer, Radiation Worker, and Process Engineer.*

Westinghouse Defense and Electronics Systems Center - *Design Engineer and Inventor*, 1982-1991, (Westinghouse President's Award, U.S. Patent) – Radar systems – Drafting and machine shop technical supervision. Design of printed circuits/wiring, castings, machined parts, and electromagnetic interference.

EDUCATION, TRAINING, AND OTHER EXPERIENCE

Ph.D., Nuclear Engineering, 2015-2019, University of South Carolina (Classes complete, PhD research in process, which is, in fact, this proposed research).

Ph.D., M.S., Mechanical Engineering, 2005, 2002, University of South Carolina.

B.S., Mechanical Engineering, 1982, Johns Hopkins University.

Nuclear Reactor Computer Design Codes, 2017, Reactor Physics, Shielding, Thermal Hydraulics, Reactor Uncertainty Analysis, Accident Analysis, AFT Impulse, Ansys, Autodyne, and Fluent – U. of Barcelona, Paris, U. of Illinois, Idaho, Georgia, Boston, Oak Ridge National Lab, U.S. NRC (410 hours).

Combustion Engineering, 2017-2018, Princeton University – Combustion Institute (80 hour course).

Project Management Professional Training, 2019, Project Management Institute (32 hour course)

International Nuclear Law Essentials, 2018, Singapore, Nuclear Energy Agency (40 hour course).

Nuclear Process Engineer Qualification Cards, SRR, SRNL – Oral Boards - Nuclear processes; Radioactive waste processing; Fuel reprocessing; Industrial equipment; Compressors; Electrical, Steam, Air, Diesel, and Vacuum systems; Calibrations; and Instrumentation (3500 hours of classes).

ASME, Piping and Pressure Vessels, (210 hours of classes) Design, fabrication, inspection, and testing.

National Codes and Standards: NRC, MIL-STD's, DOE, Hydraulic Institute, IAEA, ANSI, API, ASME, ASTM, DOD, ISO, NACE, NFPA, OSHA, NEC, NBIC, Guide to Uncertainty Measurements, and NIST.

National Association of Corrosion Engineers: Internal Corrosion, Coatings, Corrosion Design, Cathodic Protection (280 hrs).

Journeyman Sheet Metal Mechanic: Apprenticeship – Indenture papers - Metal construction (4 years).

Qualified Electrician and HVAC Mechanic: Savannah River Site, S.C. (280 hours of classes).

Welder, Carpenter, Steeplejack, Iron Worker, and Shipbuilder, 1971-1982, Welding classes - 1000 hours. Construction worker for buildings / high rises, ships, duct work, piping, and metal structures.

TEACHING (ASME and Savannah River Site nuclear facility)

Water Hammer, Fluid Mechanics, Pumps, Piping Design, Vibration Analysis, and Failure Analysis.

PUBLICATIONS (85+)

ASME Engineering Text Book, "*Fluid Mechanics, Water Hammer, Dynamic Stresses, and Piping Design*".

Technical Articles, ASME Mechanical Engineering Magazine, Mensa World Journal, plus Conference and Honors Journal Publications (ANS, ASME, AICHE, AWWA, BHR Group, DOE, Pump User's Symposium, Hydraulic Institute, and Elsevier).

PROFESSIONAL SOCIETY MEMBERSHIPS

American Society of Mechanical Engineers (ASME*)*

- **ASME Fellow -** Award for outstanding engineering accomplishments (4 ASME Awards for Service).
- **Voting Committee Member** for ASME B31 and B31.3 Process Piping; and Section VIII Boiler and Pressure Vessel Code Committee for high pressure systems.
- **Past Committee Chair and Technical Reviewer** for numerous conference and journal publications.

Society Memberships: ASME, The Combustion Institute, the American Nuclear Society, the American Water Works Association, and the National Association of Corrosion Engineers.

Mensa - 2015, Mensa Award for Intellectual Achievement for "Fire and Explosions Research".

PUBLICATIONS

Leishear, Robert A., Sole Author for the following work.

--------- 2019, "The Autoignition of Nuclear Power Plant Explosions", Journal of Nuclear Engineering and Radiation Technology, American Society of Mechanical Engineers, N.Y, N.Y.

--------- 2019, "Water Hammer Breaks Water Mains", Journal of Pressure Vessel Technology, American Society of Mechanical Engineers, New York, New York.

--------- 2019, "The Primary Cause of Oil and Gas pipeline Explosions", Empowering Pumps and Equipment eMagazine, Tuscaloosa, Al.

--------- 2017, "Nuclear Power Plant Fires and Explosions, I, Plant Design and Hydrogen Ignition", Pressure Vessels and Piping Conference, American Society of Mechanical Engineers, New York, New York.

--------- 2017, "Nuclear Power Plant Fires and Explosions, II, Hydrogen Ignition Overview", Pressure Vessels and Piping Conference, American Society of Mechanical Engineers, N.Y, N.Y.

--------- 2017, "Nuclear Power Plant Fires and Explosions, III, Hamaoka Piping Explosion", Pressure Vessels and Piping Conference, American Society of Mechanical Engineers, N.Y, N.Y.

--------- 2017, "Nuclear Power Plant Fires and Explosions, IV, Water Hammer Ignition Mechanisms", Pressure Vessels and Piping Conference, American Society of Mechanical Engineers, New York, New York.

--------- 2013, *Fluid Mechanics, Water Hammer, Dynamic Stresses, and Piping Design*, ASME Press engineering textbook, American Society of Mechanical Engineers, N.Y, N.Y, pp. 1-444.

--------- 2013, "From Water Hammer to Ignition, The Spark That Ignited Three Mile Island Burst from a Safety Valve", Mechanical Engineering Magazine, American Society of Mechanical Engineers, New York, New York, pp. 46-49.

--------- 2013, "Explosions: A Fresh Look at Chernobyl, Three Mile Island, the Gulf Oil Spill, and Fukushima Daiichi", Mensa World Journal, Mensa International Limited, Caythorpe, United Kingdom, p. 6.

THE AUTOIGNITION OF NUCLEAR POWER PLANT EXPLOSIONS

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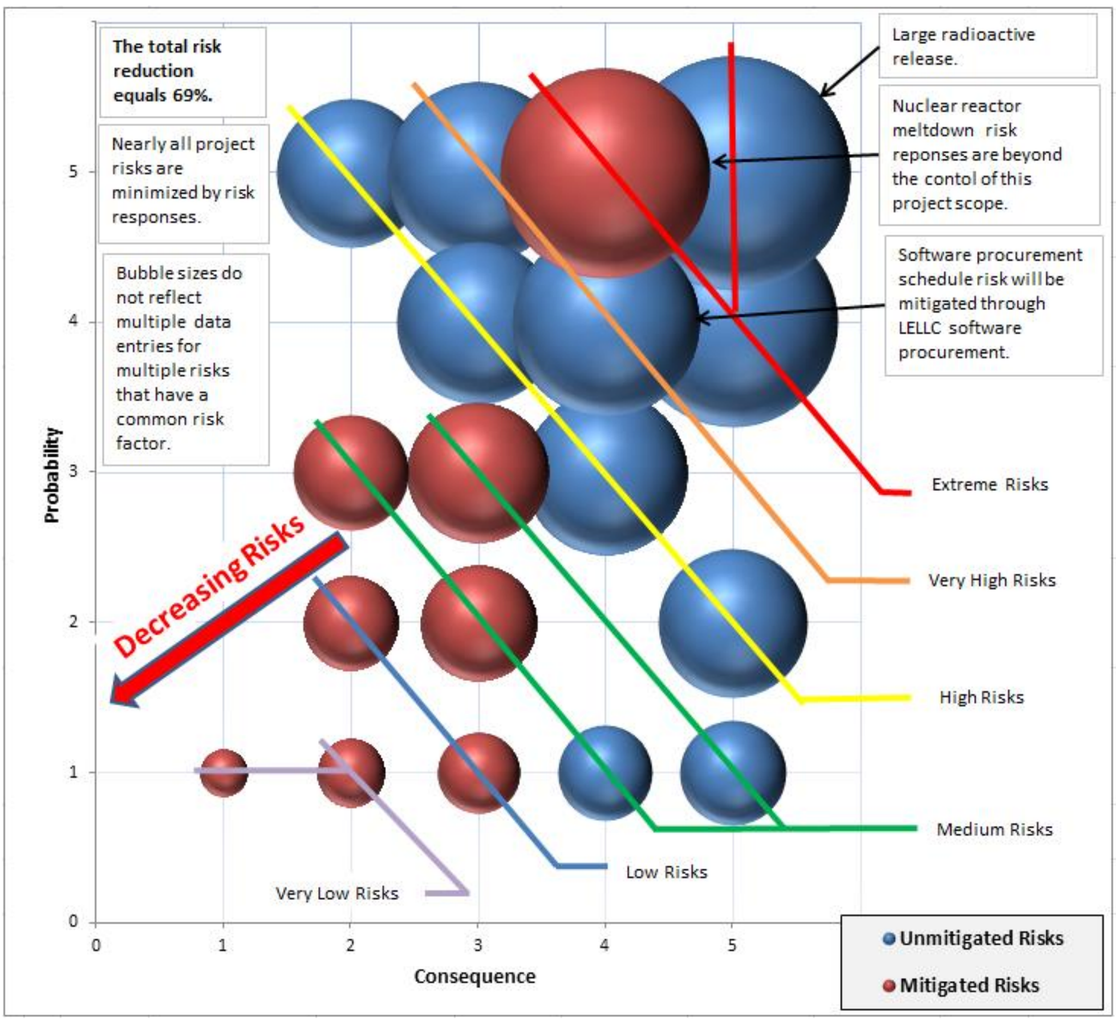

Project Risk Reductions

Submitted to the DOE, Office of Nuclear Energy, 10/30/2019.

PROJECT MANAGEMENT PLAN

Applicant, Principal Investigator, Sole Researcher:
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Leishear Engineering, LLC, Email - Leishear @aol.com, Website – leishearengineeringllc.com, 803-641-6753

Contents

EXECUTIVE SUMMARY

The facts are clear – lives are at stake – a nuclear reactor accident can happen at any time, and there is a one in two probability of a Fukushima type radioactive blast into the air and across the globe when this meltdown occurs. At this moment in history Dr. Leishear is the leading researcher to stop this disaster – there will be followers later but not now. Not only can this explosion be prevented, but yearly deaths and multi-billion dollar damages can be stopped as well, where validation investigations of gas pipeline explosions and water hammer induced water main breaks are required as part of this research. Evaluations of gas pipeline explosions and water main breaks are required to validate nuclear accident explosion models due to the limited, available experimental data for nuclear plant systems. This research project is the next step to prevent disaster. These claims may seem bold, but Dr. Leishear voluntarily dedicates his life as proof – he has the training, skills, knowledge, and drive to finish this in-process research, and this research will prevent needless deaths during environmental nightmares. The merit of this work is the question, and the magnitude of my theory answers that question and earns the approval of this grant request. To prove this statement, consider the required research to stop death and destruction.

Figure 1: Nuclear Power Plant Pump Restarts Autoignite Explosions (Fukushima shown)

Objectives

The objective of this research is to quantitatively prove a common cause for nuclear power plant explosions and to investigate preventive actions. This research explains ongoing explosions in US nuclear power plants, Fukushima explosions, a Three Mile Island hydrogen explosion, and other nuclear power plant piping explosions around the world. These accidents are caused by compressing flammable hydrogen and oxygen to autoignition and explosion, where this common mode dieseling process, called the Leishear Explosion Theory, is primarily initiated by pump and valve operations. That is, explosive new technology for nuclear reactors proves that hundreds of ongoing smaller explosions and previous large scale catastrophic explosions have a common cause. Although conference and journal publications have proven the basic theory, existing publications are inadequate to completely understand the complex combustion processes, and those publications are inadequate to recommend preventive actions[1].

Project Goals

The project goals are to investigate the Three Mile Island (TMI-2) meltdown and explosion, a Hamaoka, Japan piping explosion, and smaller gas explosions in US nuclear reactor systems. This proposed two year project will prevent explosions at existing and future advanced reactor nuclear power plants. To do so, a series of computer simulations will be performed that will investigate interrelated issues that will include reactor physics, reactor chemistry, thermal hydraulics, combustion, and resultant explosions.

The resultant research will include seven, conference ready, publications and animated computer models of reactor processes and explosions. Preventive actions will be recommended during this research, where complex reactor system models will provide new insights into the explosion processes. This research is applicable to the existing U.S. reactor fleet, as well as future nuclear reactor designs, reactors throughout the world, and is incidentally applicable to gas pipeline explosions and water main breaks.

Expected Results

The outcomes of this research will include recommendations to prevent nuclear reactor piping damages due to small-scale explosions, recommendations for regulatory changes to minimize risks for off-normal reactor meltdown accidents, recommendations to prevent large scale radioactive releases during meltdown events, and parallel recommendations to stop gas pipeline explosions that kill people every year. To date, regulatory agencies have failed to recognize these scientific advancements, where explosions inside piping have been misunderstood since the 1950s, and large explosions associated with nuclear reactor meltdowns are misunderstood as well. In fact, present US NRC regulations do not provide adequate safety regulations to evaluate reactor accidents with respect to explosions, and in-process research shows that the next nuclear reactor meltdown can happen any time between now and 2038, with a one in two probability of a large radioactive release like Fukushima. Preventing an impending meltdown is beyond the scope of this research, but a major radioactive release can be prevented in the event of a meltdown. In short, the primary, long-term goal of this research is to change existing safety requirements through legislation to regulate nuclear power plant design and operation to ensure safe nuclear reactor operations.

Table 1: Risk Assessment Criteria / Risk Factors

		Consequence				
		1, Insignificant	2, Minor	3, Significant	4, Major	5, Severe
Frequency	5, Almost Certain	5 , Medium	10 , High	15 , Very High	20 , Extreme	25 , Extreme
	4, Likely	4 , Medium	8 , Medium	12 , High	16 , Very High	20 , Extreme
	3, Moderate	3, Low	6 , Medium	9 , Medium	12 , High	15, Very High
	2, Unlikely	2, Very Low	4, Low	6 , Medium	8 , Medium	10 , High
	1, Rare	1, Very Low	2, Very Low	3, Low	4 , Medium	5 , Medium

[1] This explosion cause also explains off-shore oil rig explosions, oil pipeline explosions, and gas pipeline explosions, where most petroleum industry explosions, except gas pipeline explosions, are outside the scope of this research.

PROJECT MANAGEMENT PLAN OVERVIEW (PMP)

As required by the FOA, "this PMP will be updated by the recipient as the project progresses, and the recipient must use this plan to report schedule and budget variances. During project performance, the recipient will report the Milestone Status as part of the required quarterly Progress Report." Discussions of risks and schedule follow, which include milestones and decision points for project control.

RISK MANAGEMENT

Based on research to date, a qualitative risk assessment based on expert, engineering judgement was performed for this research, and the results are provided in Tables 1 and 2, and results are further explained in the Project Narrative. Table 1 shows the measures of risk assessment, which are the consequence of an action or event, and the probability of that event or process. Both probabilities and consequences are both rated between1 and a maximum of 5, and risk factors are identified and color coded from very low risk to extreme risk. Table 2 provides the risks and risk responses identified to date along with risk factors to compare unmitigated risk factors to mitigated risk factors. These risk factors vary from 1 for the lowest risks to 25 for extreme risks, i.e., risk vary from low probability and insignificant consequences up to the Fukushima explosions for worse case risks. The probability and consequence values were based on engineering / expert judgement, based on years of research and education that were executed to prepare for this modeling research.

Risk Summary

In short, this research is imperative to stop death and destruction, which represent the highest risks with respect to this research. The highest risks are associated with accidents that kill people, i.e., nuclear power plant and gas pipeline explosions. Most risks are mitigated by reducing risk responses to low or very low values, but a few risks are not. Of paramount importance to this project, the risk of not performing this research dwarfs the risks due to other risks.

Extreme risks

1) A nuclear reactor meltdown predicted before 2038 is outside this research scope, but indirect deaths and significant damages can be averted, or mitigated, by prevention of large radioactive releases.

Very high risks

2) Modeling software, Fluent, represents and very high schedule risk that requires advance payments by DOE.

Medium risks

3) Melcor modeling would improve results, but schedule and unavailability of Sandia support are prohibitive.
4) Relap5 models still require data.
    a. The TMI-2 Safety Analysis Report may be obtained from NRC by DOE.
    b. TMI-1 analysis may be an option.
    c. TMI-2 data may be found in the literature.
5) Hydrogen generation models will not be exact.
    a. Models are unavailable for thermolysis.
    b. Melcor models are not planned for use.
    c. Frapcon and Fraptran are available for steady state and non-steady state hydrogen generation respectively.
6) CPU time is uncertain, and the schedule may be affected.
7) Subcontractor (Simutech) costs will not be confirmed until after DOE contract award.

Milestone Log, Decision Point Criteria, Project Funding Profile, Project Costing Profile, and Schedule

Milestones consist of the completion of a series of draft technical papers that document research progress, as listed in Table 3. Also, the effects of risk mitigation are shown in Fig. 2. Decision point criteria are listed in Table 4. Costing and Funding Profiles are shown in Table 5. All milestones are go-no go criteria, and resolutions of any technical issues are required. At that time, decisions may be made to determine if schedule logic ties should be broken to permit parallel research paths as research proceeds. The schedule is shown in Fig. 3.

Table 2: Risk Matrix

No.	**Risks** (R01 -R07 are external risks - all other risks are project technical risks and project organizational risks)	Categories	Unmitigated Consequence	Unmitigated Probability	Unmitigated Risk Factor	Risk Responses	Mitigated Consequence	Mitigated Probability	Mitigated Risk Factor
R01	Large radioactive releases from explosions.	Technical	5	5	25	Mitigate: Preventive actions from this research will minimize large radioactive releases. ASME paper in publication to explain radioactive releases and stop imminent deaths. ASME and ANS papers were published to explain radioactive releases.	2	1	2
R02	Gas pipeline explosion.	Technical	5	5	25	Mitigate: Preventive actions from this research will minimize gas pipeline explosions and stop continuing deaths that occur every year. A gas pipeline explosion paper was published to explain pipeline explosions.	2	1	2
R03	Nuclear reactor meltdown.	Technical	4	5	20	Accept: No actions to prevent meltdowns during this research. However, TMI accident conditions will be modeled. Model scaling may be required for TMI. Predictions for the next nuclear reactor meltdown and explosion is in review for ASME publication.	4	5	20
R04	Gas pipeline cracks from explosions.	Technical	3	5	15	Mitigate: Preventive actions from this research will stop reactor piping damages and potential deaths (Published theory).	2	1	2
R05	Nuclear reactor system piping cracks from explosions.	Technical	2	5	10	Mitigate: Preventive actions from this research will stop piping explosions. Inaction results in continuing damages to the US nuclear reactor fleet plus potential damages to future reactors (Published by BHR Group).	2	1	2
R06	Water main breaks from fluid transients.	Technical	4	5	20	Miitigate: This research will improve previous recommendations in publication to stop multi-billion dollar U.S. damages due to fewer breaks, i.e., this rsearch will provide a better technical understanding of water main breaks. R. Leishear is the Project Manager for an in-process ASME standard on water hammer. Numerous papers and an ASME book have already been published on this topic. Risks reduced by earlier research.	2	1	2
R07	Lack of technology - New technical discoveries.	Technical	4	4	16	Exploit: New discoveries are an integral part of new research, where the full scope of research considered here has never been performed. Discoveries have already been published from this research, as part of an extensive education effort to support this research.	2	1	2
R08	Melcor modeling of meltdown conditions	Technical	3	3	9	Eliminate: Melcor models would provide additional insights, but the unknowns within Melcor exclude its use from this research. OR Transfer: DOE could obtain Melcor modeling data from Sandia and extend the schedule to incorporate Melcor estimates of hydrogen generation during different phases of the TMI-2 explosion.	3	3	9
R09	Unavailabity of computer codes to model reactor startup from meltdown conditions.	Technical	5	3		Mitigate: There are no available codes that can model restart after a meltdown. Interrelated models will reduce this risk.	2	2	4
R10	Trace modeling of thermal hydraulics	Technical, Schedule	3	2	6	Eliminate: Trace does not accurately model sonic flow, and Trace is not easy to use initially, which could result in significant schedule delays.	0	0	0
R11	NRC Relap5 model reflects TMI-1 Configuration	Technical	3	2	6	Mitigate: Find TMI-2 differences in the literarure. OR Transfer: DOE can obtain TMI-2 SAR from the NRC. OR Accept: Use a TMI-1 model to determine potential meldown conditions for a slightly different reactor design.	3	2	6
R12	Hydrogen generation		3	2	6	Accept: Comprehensive hydrogen generation modeling cannot be performed. Thermolysis models are unavailable. Melcor models are not presently planned for use unless DOE extends schedule and obtains Melcor data from Sandia. Frapcon is avaialable to evaluate steady state opearations, and Fraptran is available to evaluate non-steady state conditions.	3	2	6
R13	Loss of R. Leishear. Research stops.	Resources	5	1	5	Mitigate: Successive, real time, publications will reduce the risk of lost research data. Others can continue through separate research in the event of a death. The probabilty of death during this research project is less than 5%.	3	1	3
R14	Management staffing.	Resources	5	1		Exploit: Part time Business Manager services of Janet Leishear will reduce operating costs.	1	1	1
R15	Loss of J. Leishear. Administrative support stops.	Resources, Schedule	3	1	3	Mitigate: R. Leishear will step in. Schedule would be affected - accept this schedule risk. The probabilty of death during research is less than 5%.	2	1	2
R16	Simutech modeling staff availability for specialized training.	Resouces, Schedule	2	2	4	Accept: Simutech will be contracted if a DOE proposal is approved.	2	2	4
R17	R. Leishear illness, schedule delay.	Schedule	2	2	4	Accept. Overtime may be an option.	2	2	4
R18	J. Leishear illness, schedule delay.	Schedule	2	2	4	Accept.Ovetime may be an option.	2	2	4
R19	Thermal hydraulic model delays.	Schedule	4	3	12	Mitigate: TMI Reactor core models that were used in previous classes will again be used here. Also, the NRC provided a TMI-1 model for the rest of the reactor system, which needs to be verified for accuracy. Dr. Leishear will attend Matlab programming to facilitate NRC models.	2	2	4

R20	Fluent combustion model devlopment delays.	Schedule	4	3	12	Avoid: Simutech, a Fluent contractor, will provide specialized training for pilot scale modeling to expedite the schedule.	2	2	4
R21	LELLC combustion modeling results.	Schedule	5	2	10	Avoid: LELLC will procure Fluent, Ansys, LS Dyna, and AFT Impulse licenses to support this research wih full access to Fluent and AFT staff for technical consultations.	2	1	2
R22	LELLC reactor modeling results.	Schedule	4	3	12	Avoid: All required reactor software has been purchased, and required classes to operate this software have been attended.	2	1	2
R23	Frapcon	Schedule	3	3	9	Mitigate: If Frapcon modeling becomes a schedule concern, hand calculations will be used.	2	1	2
R24	Fraptran	Schedule	3	3	9	Mitigate: If Fraptran modeling becomes a schedule concern, hand calculations will be used.	2	1	2
R25	Fluent procurement.	Schedule	4	4	16	Accept: Advanced DOE payments are required to purchase Fluent software. LELLC will retain software ownership for subsequent research for potential future grants to further this research. Another option is to rearrange the schedule to ensure that funding is available from LELLC wages, where explosions understanding would be delayed. Thissecond option is not preferred, since a progressing explosion understanding will provide addtional insights into TMI modeling to ensure that TMI models are adequate. LELLC wil provide advance payment with 30 day reimbursement from DOE.	2	2	4
R26	CPU time	Schedule	3	3	9	Accept: Since the models have not been set up, the CPU time required to complete the models is unknown, but could be 2 to 4 weeks, or longer, for some models. If the CPU time is excessive this risk can be partially mitigated by switching to different job assignments while CPU's are running. LES models will be initially performed to scope the combustion problems, followed ny RANS simulations to provide better model accuracy.	3	3	9
R27	Unavailable software to fully model TMI reactor meltdown to explosion sequence.	Quality Assurance	5	5	25	Mitigate: Relap5 and Fraptran will be used to model some hydrogen generation and hydrogen location at the time of the accident. Then, this output data will be input into Fluent. Extensive PI education and training was completed to ensure that selected models can successfully complete this research project to save lives and property.	2	1	2
R28	Software accuracy.	Quality Assurance	5	4	20	Mitigate: NRC and NQA-1 approved software will be used. Some model fidelity will be lost due to RANS simulations, but the cost for high resolution numerical models (DNS) approaches $1,000,000, which is outside the scope of this research and schedule. Accept the accuracy of RANS modeling.	2	1	2
R29	TMI Nuclear reaction modeling accuracy.	Quality Assurance	4	4	16	Mitigate: Parcs and Relap5 reactor data is available for TMI normal operating pressures and temperatures. High temperatures require additional modeling, where courses were attended to address this issue.	1	1	1
R30	Sonic flow through safety valve accuracy.	Quality Assurance	3	2	6	Avoid: Relap5 selected since Trace does not correctly model sonic flow.	2	1	2
R31	Gas compression model accuracy since Relap5 does not adequately model gas compression.	Quality Assurance	3	5	15	Avoid: Data from Relap5 will be used as input to Fluent models for gas compression and combustion modeling.	2	2	4
R32	Validation of Parcs and Relap5 TMI models. Complete model validation cannot be performed.	Quality Assurance	3	5	15	Mitigate: Partial model validation for Relap5 and Parcs will be compared to NRC steam line break and reactivity models, which are published in the literature.	2	2	4
R33	Performance of Fraptan and Frapcon models.	Quality Assurance	3	2	6	Accept: Dr. Leishear has no experience yet with these programs, and training is unavailable.	3	2	6
R34	Validation of small explosion models.	Quality Assurance	3	2	6	Mitigate: Since there is much experimental data on methane combustion and explosions, gas pipeline explosions will be used for model validation to understand explosion dynamics, using Fluent and LS Dyna. Also, Hamaoka explosion photos will be compared to LS Dyna explosion model performance for model validation.	2	1	2
R35	Validation of piping stresses during small explosions.	Quality Assurance	3	3	9	Mitigate: With an understanding of square waves caused by water hammer, water main breaks will be investigated with respect to damping and wave speeds for large diameter piping (12"-36" dia.). Explosion waves are nearly triangular and mathemetical correlations can be readily used to extrapolate water hammer conclusions to explosions. That is, much information is available to validate water main models, where validations can be extrpolated to explosion analyses - proof by similarity	2	1	2
R36	Final explosion models cannot be fully validated.	Quality Assurance	4	4	16	Mitigate: Although model errors cannot be confirmed without experiment, Fluent, Ansys, and LS Dyna are accepted world-wide as competent computer modeling codes for combustion, sturctural response, and fluid flow. Gas pipeline explosion models can be validated through the evaluation of explosion craters, which are documented in the literature.	2	3	6
R37	TMI Hydrogen generation model validation.	Quality Assurance	3	2	6	Mitigate: Fraptran will be used to determine hydrogen genration up to the time of the meltdown, and results will be compared with proven calculation techniques.	2	2	4
R38	Technical peer reviews.	Quality Assurance	3	2	6	Mitigate: All publications will not have technical peer reviews before project completion, but those publications completed early will be peer reviewed for conferences, and B31 Code Committteee meetings will be attended to further engineering community interactions with respect to this research.	2	2	4
R39	Data loss due to viruses, hacking, or environmental office damages.	Quality Assurance	4	4	16	Miigate: Data backups will be routinely performed. Anti-virus protection installed on computers. Procure computer backup services in addition to flash drives.	2	1	2
R40	Lack of Quality Assurance.	Quality Assurance	3	4	12	Avoid: The LELLC PI has experience as a Quality Assurance Engineer, implementing NQA-1 requirements into plant procedures and employee performance.	1	1	1
R41	Simutech contract performance for LELLC.	Communications	3	2	6	Accept: SimuTech is a contractor service provider for Fluent products, which are required for this research.	3	2	6

R42	LELLC contract performance for DOE.	Communications	4	3	12	Sharing: Quarterly reports will be provided to DOE, as required by contract, for costs, schedule, risks, and technical reports in the form of draft conference publications.	2	1	2
R43	LELLC contract performance for DOE.	Stakeholder management	4	3	12	Mitigate / Avoid: Extensive PI experience with multiple project stakeholders at Savannah River Site / Savannah River National Laboratory.	3	1	3
R44	LELLC risk management.	Monitoring, controlling, and executing risks	4	3	12	Mitigate: A risk register will be maintained to monitor risks, and aapropriate decision points have been established in the schedule to control risks and implement risk responses.	2	2	4
R45	Cost overruns.	Cost management	4	3	12	Mitigate: Costs will be monitored during work performance and invoices will be provided on a 30 day cycle for DOE payments to LELLC and modeling and research, for LELLC training, and for Fluent procurement.	2	2	4
R46	Funding reserve analysis.	Cost management	4	3	12	Mitigate: DOE reimbursement will be paid within 30 days for software procurement, insurance payments, and accountant payments to ensure that money rerverves do not become a problem.	1	1	1
R47	Civil law suit actions resulting from research publications.	Cost management	4	1	4	Mitigate: Liability insurance will be purchased.	1	1	1
R48	Simutech contract costs.	Cost management	3	2	6	Accept: Simutech costs may changes depending on modeling training progress. Per DOE, LELLC will absorb cost overruns by SimuTech.	3	2	6
R49	DOE Auditable cost accounting.	Cost management	3	3	9	Mitigate: An accountant, Andrew Wilder of Rhodes Murphy, will set up a DOE compliant cost accounting system for LELLC.	1	1	1
R50	Cost accounting records.	Cost management	3	3	9	Mitigate: Dr. Leishear and J. Leishear will attend Quick Books training so that either one may perform required accounting ansd scheduling tasks.	1	1	1
R51	Project failure to achieve expected results.	Project management	5	5	25	Mitigate: The overall risk assessment process ensures project success - success is better than failure. Failure of this project will result in continuing deaths and destruction.	2	2	4
R52	Scope change / Schedule delay .	Project management	4	4	16	Mitigate: Extensive PI experience in project management, cost estimating, and scheduling minimizes potential project risks. Attended Project Management Professional training to prepare for this contract. Change request method TBD.	2	2	4
R53	Computer crash.	Project management	4	3	12	Mitigate: Add budget to procure a second computer in the case of computer damage, e.g. crash, where this computer wll also be used to mitigate schedule risks if program run time is excessive.	1	1	1
R54	Project delays can cause cost and schedule overruns if decision points lead to findings that require additional research.	Project management	3	3	9	Mitigate: Add budget to procure for software during Year 3, if schdule slips.	2	2	4
	Total risk.				588				184
	Percent decrease in total risk due to risk responses.					68.71%			

Table 2, Risk Matrix Notes[2]:

1) Consequence and probability ratings are based on expert / engineering judgement, where a study was performed to evaluate risks and modeling strategies and the relative project importance of different risk criteria were compared. 2) For accident conditions (external events), mitigation effects for probabilities and consequences were assumed to result from regulatory implementation of recommendations provided by this research, i.e., government regulators are assumed to implement recommendations from this research. 3) The probabilities for calculations and validations represent the likelihood of an error, rather than the likelihood of an event occurrence. 4) Decreasing the risk factor decreases project uncertainty and increases project success probability or project value. 5) Integer values are assigned for consequence and probability estimates, where risk factors are the product of the consequence multiplied times the probability. 6) Risk strategies are based on extensive engineering experience, pertinent engineering publications, and extensive research to background this project, where risk strategies for DOE and LELLC joint risk responses include Sharing, Accepting, Avoiding, Exploiting, Eliminating, and Mitigating.

[2] From the FOA Q&A, The applicant may use the font and font size of their choosing for exhibits, graphics, and tables, as long as these items are adequately legible to the reviewers (i.e., will not require the use of magnification to read). See SF424RR for detailed risk assessment and cost calculations.

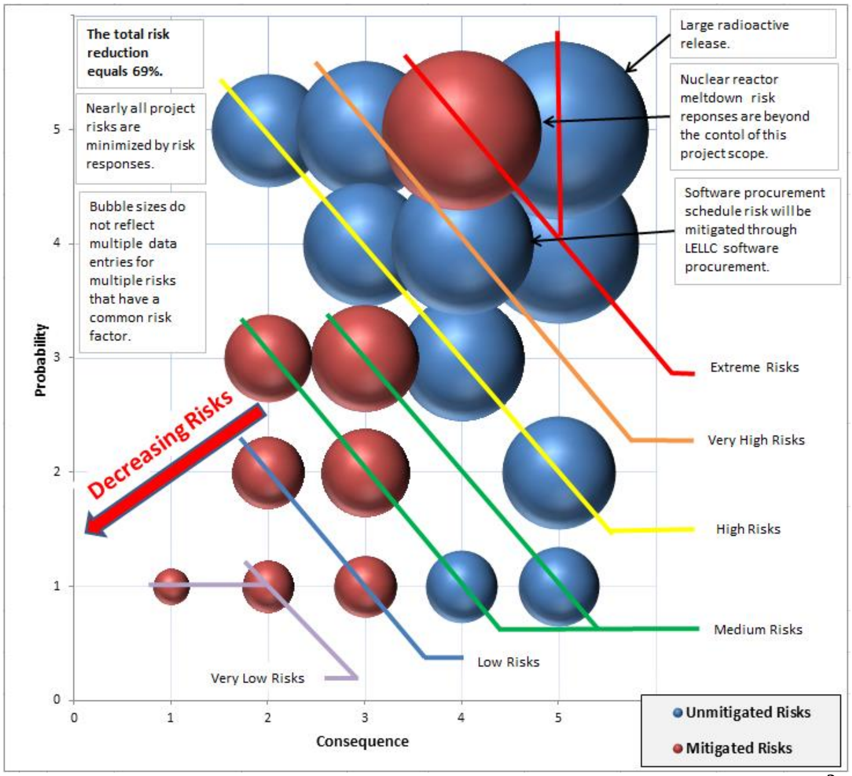

Figure 2: Reduction of Unmitigated Risks to Mitigated Risks[2]

Table 3: Project Milestones[2]

Milestone	Planned Completion Date
Year 1	
Paper 1: "Gas Pipeline Explosion Models"	Week 18
Paper 2: Gas Accumulation Events: Fatigue Cracks and Ruptures	Week 29
Year 2	
Paper 3: "TMI Normal Operations"	Week 63
Paper 4: "TMI Steam Line Failure and Reactivity Accident Validations"	Week 74
Paper 5: "Hydrogen Generation During TMI Meltdown Conditions"	Week 85
Paper 6: "Hamaoka Nuclear Reactor, Hydrogen Explosion Modeling"	Week 97
Paper 7: "TMI Nuclear Reactor, Hydrogen Explosion Modeling"	Week 100

Table 4: Decision Points and Success Criteria[2]

Decision Points	Success Criteria
1 - Quantitatively determine if explosion models are adequate, using comparisons between models and gas pipeline explosion results.	To quantify model accuracy, compare the San Bruno Fluent models to published catastrophic piping explosion photos
Interim Assessment, Year 1	Evaluate San Bruno explosion results.
2 - Quantitatively determine if piping fatigue failure models are adequate, using uncertainty analyses and water hammer experimental measurements.	To quantify model accuracy, compare Fluent model results to experimental SRS research results for piping strains, caused by water hammer.
3 - Quantitatively determine if loss of coolant and reactivity analyses are adequate, using uncertainty analysis and comparisons between models and published DOE results.	To quantify model accuracy, compare Parcs - Relap5 results to published NRC results for reactivity and steam piping accidents.
4 - Quantitatively determine if Hamaoka analyses are adequate, using comparisons between models and exploded piping.	To quantify model accuracy, compare Hamaoka piping explosion Fluent model results to published accident photos of the exploded piping.
Final Assessment, Year 2	Evaluate fatigue models, Hamaoka and TMI accidents, and a reactivity accident.

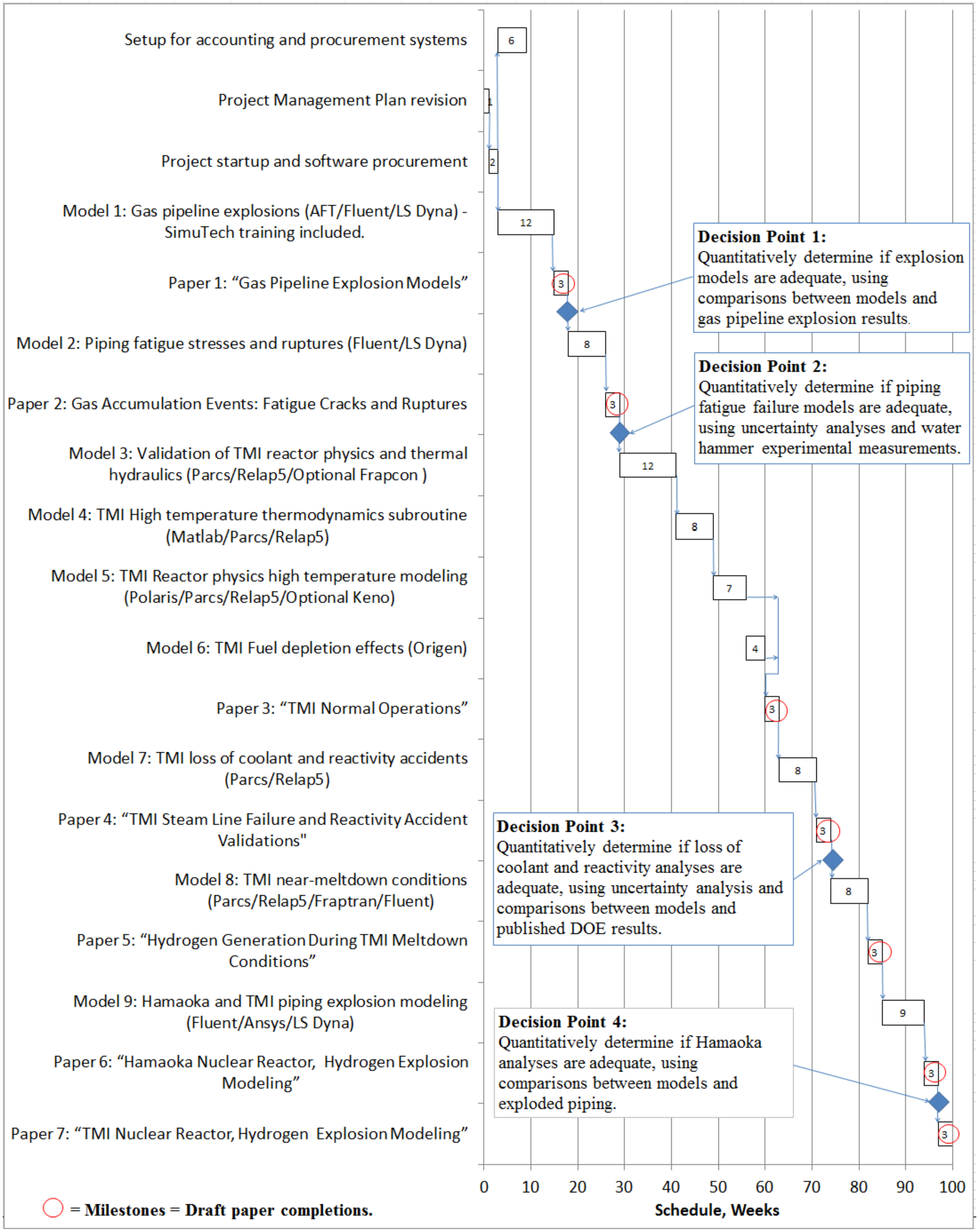

Figure 3: Project Schedule[2]