To: **DOE, Inspector General**
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DOE COVER UP OF EXPLOSION DANGERS IN U.S. NUCLEAR POWER PLANTS

Issues: Mismanagement of DOE Programs
Environment, Health, and Safety Violation
False Statements and False Claims
Ethics Violations

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EXECUTIVE SUMMARY

The DOE, Idaho Operations Office improperly, unethically, and dishonestly dismissed a research grant proposal to prevent explosions in nuclear power plants, and this decision will directly result in loss of life and disastrous environmental damages, i.e., this DOE decision can kill people and spew radioactive contamination across U.S. property. To dismiss this research proposal, the DOE falsely claimed that the prevention of nuclear power plant explosions does not "propose innovative technology development to improve the capability of the existing fleet" of nuclear power plants. That is, in blocking this grant, the DOE made this false claim and other false claims (dishonest, untruthful actions) to support their errant decision that violated their own procedures, ie., Funding Opportunity Announcement (an improper action). These actions constitute a cover up (an unethical action and lack of integrity) of an important safety issue that can result in loss of life, property damage, and major environmental damages, and this unethical DOE blockage of needed research is a threat to public safety. The issues are described as follows.

1.0) U.S. NRC malfeasance with respect to nuclear power plant explosions is discussed in detail in Appendix A, p. 9.
2.0) I have voluntarily spent the past four years investigating nuclear power plant explosions to prove that explosions have a common preventable cause. This research has been voluntary at a personal cost of more than $130,000 for pertinent publication and training costs to perform and document this research.
3.0) DOE approved an Abstract to perform this research in accordance with their Funding Opportunity Announcement (FOA) (DE-FOA-0001817, U.S., Industry Opportunities for Advanced Nuclear Technology Development, Application ARD 20.2-21608).
4.0) The original proposal included experimental explosion testing to better understand explosion theory and explosion prevention, and I spent several months designing explosion test equipment.
5.0) DOE nonfeasance caused the explosions contractor to withdraw from this research.
6.0) Accordingly, the scope of the research changed, and details of planned computer modeling were modified to ensure that results could be reasonably validated without explosion tests. Future experimental research was recommended in the final Grant Proposal.
7.0) The intent of preventing explosions and saving lives was not changed at all.
8.0) The completed grant proposal was submitted.
9.0) DOE dismissed the entire proposal claiming that it did not meet the FOA, where DOE had already approved this research plan with respect to FOA compliance. DOE refuses to explain this decision, which blocks important research to prevent nuclear power plant explosions in the U.S. False claims were made to support their decision.
10.0) This unethical DOE malfeasance is tantamount to a cover up of U.S. nuclear power plant explosion dangers.
11.0) These actions constitute fraud, waste, and abuse due to mismanagement.

12.0) My request is that DOE fairly consider this grant proposal to prevent loss of life, damage to property, and damage to the environment. Nuclear power plant explosions, large and small, can be stopped.

13.0) Please expedite this request, since FOA funding expires in December, 2020.

FINDINGS

1.0) **NRC Malfeasance and Cover Up with Respect to Explosions:** The NRC has responded to multiple correspondence since 2011, but the NRC refused to respond to several correspondence during the past two years, including an email to allegatios@nrc.gov that was titled "The NRC Cover Up". Details of the explosion cause and the history of my correspondence with the NRC on important safety issues are included in Appendix A, p. 9. Since this research concerns loss of life, the NRC failure to respond to these allegations and take action on these safety allegations constitutes malfeasance, which is defined as wrongdoing, especially by a public official. Also, the NRC misrepresented facts for forty years to convince the public that a fire occurred at Three Mile Island rather than an explosion that really occurred. To do so, important information was deleted from TMI accident investigation reports for the NRC to claim these false conclusions as discussed in Appendix A, p. 9. Together these actions constitute malfeasance that endangers the public welfare.

Figure 1: A Fukushima, Japan nuclear power plant explosion was caused by pump startups. Based on 11 previous meltdowns since the reactor fleet started operation in the 1950s, the next nuclear reactor meltdown is predicted before 2039 with a one in two probability of an explosion (11% probability of a U.S. explosion during the life of the existing fleet) (Appendix A, p. 9).

Figure 2: A valve operation in Hamaoka, Japan autoignited hydrogen and caused a piping explosion in a 6 inch diameter, ¼ inch thick steel pipe. Smaller explosions continue to occur in the U.S. reactor fleet and throughout the world (Appendix A, p. 9).

Figure 3: Pump operations and check valve closure in Brunsbuttel, Germany autoignited hydrogen and exploded a 6 inch diameter, ¼ inch thick steel pipe.

2.0) **Explosions Research by Robert A. Leishear:** Four years of volunteer research proves that preventable explosions in nuclear power plants have a common, preventable cause. Pump startup and valve operations compress flammable hydrogen that is created during normal nuclear reactor operations and accident conditions. When the hydrogen compresses, it heats and explodes, much like the ignition of a diesel engine. The applicability of these explosions to nuclear power plants has been clearly proven (The Leishear Explosion Theory). Pertinent explosions include the 2011 Fukushima explosions (Fig. 1) that were incorrectly claimed to be caused by unknown ignition sources, the 1979 explosions at Three Mile Island that were falsely reported by the NRC to be a fire for the past 40 years, and hundreds of continuing small explosions in U.S. nuclear reactor piping systems (Figs. 2 and 3), where the NRC incorrectly reports – to this day - that these explosions are water hammers rather than explosions. A primary statistical conclusion is that a nuclear reactor meltdown in the worldwide fleet is expected before 2039, and that there is a one in two probability of a large Fukushima type radioactive release across the surface of the earth at that time. The probability of a U.S. explosion is 11% - about one in ten – for the existing U.S. reactor fleet. Fourteen well documented, peer reviewed, engineering publications record this research as discussed in Appendix A, p. 9.

3.0) **FOA Compliance Approval by DOE:** DOE clearly stated that this research meets the FOA as stated in an email from the National Energy Technology Laboratory (NETL), John N. Augustine (DOE representative), which was dated 7/11/2018. "Your Unsolicited Proposal, entitled "Thermal Fluid Transients Cause Piping Failures and Nuclear Power Plant Fires and Explosions" has been reviewed by technical personnel at the Department of Energy (DOE), Nuclear Energy, Science and Technology. After carefully studying the proposed concept, DOE has determined that the proposal fits under a U.S. Industry Opportunities for Advanced Nuclear Technology Development FOA No. DE-FOA-0001817".

This DOE response is a very concise statement that the proposed research meets the requirements of the FOA, which are stated as follows.

"The objective of this FOA is to support innovation and competitiveness of the U.S. nuclear industry through cost-shared, cross-cutting basic/fundamental, applied R&D, and demonstration/commercial application R&D activities for all aspects of existing and advanced reactor development. These activities may include development of technologies that improve the capability of the existing fleet, methods to improve the timelines for advanced reactor deployments, the cost and schedule for delivery of nuclear products, services, and capabilities supporting these nuclear technologies, design and engineering processes, and resolution of regulatory/certification issues potentially impeding the introduction of these technologies into the marketplace. ….

- Modeling and simulation of various elements of plant life cycle;
- Procedures, processes, and methodologies that can impact operational efficiencies ….

In general, NE is seeking applications for unique/new ideas that will improve the existing fleet, the potential for future U.S. nuclear power deployment, U.S. nuclear technology leadership, and U.S. industry competiveness. …. Broad applicability to multiple reactor technologies and types".

The prevention of nuclear power plant explosions certainly improves the capability of the existing fleet by improving capabilities supporting nuclear technologies, design and engineering processes. The explosion theory presented to in Appendix A (p. 9) is applicable to all operating light-water reactor designs, and this research therefore has broad applicability to multiple reactor technologies and types. Predicted explosions are part of plant life cycle for the reactor fleet, since there have been nuclear reactor meltdowns in the worldwide fleet since the 1950s. Preventing explosions and power plant piping damages that are an ongoing problem in the U.S. fleet will improve operational efficiencies. This problem is documented in the proposal that was submitted to DOE, and was further documented in a Journal paper, titled "The Autoignition of Nuclear Power Plant Explosions", Journal of Nuclear Engineering Radiation Science and Technology, by Robert A. Leishear, 2020, American Society of Mechanical Engineers, N.Y., N.Y. This first of a kind research certainly meets the requirement to be innovative, since this author is currently the sole investigator for the prevention of nuclear power plant explosions, using the Leishear Explosion Theory.

If power plant explosions are not prevented, the U.S. nuclear industry can be permanently crippled. Preventing such an outcome certainly supports innovation and competitiveness in the U.S. nuclear industry. A DOE decision to allow future explosions to kill people is irresponsible and incompetent.

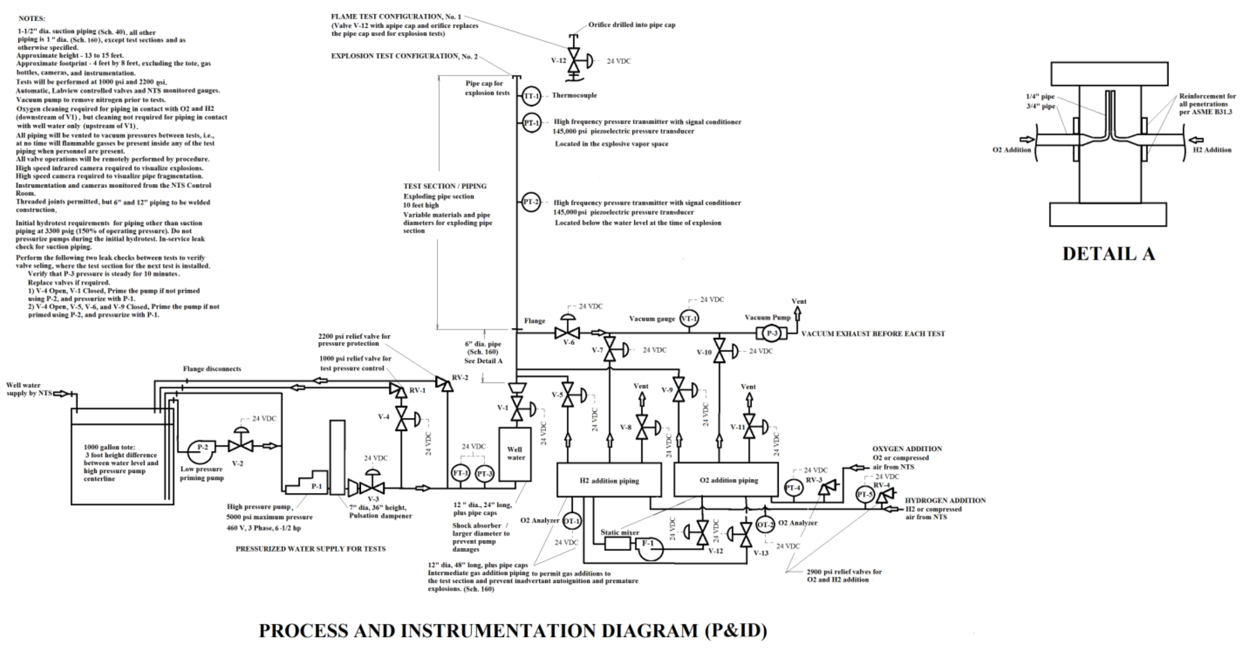

Figure 4: Final Equipment Design for Cancelled Explosion Testing

4.0) **Original Grant Proposal Scope:** The original Abstract for the Grant Proposal included explosions testing as well as computer modeling as discussed in Appendix B, p. 45. Working in misplaced good faith that the DOE FOA compliance approval was honest and reliable, several months of full time proposal research were performed to design and evaluate the complex explosions, equipment, and monitoring processes required for explosion testing. The … expressed interest in supporting this research, but … chose to work as a contractor to Leishear Engineering, LLC rather than work as a direct contractor with DOE. The final design is shown in Fig. 4.

5.0) **DOE Nonfeasance Forces Change of Scope for Planned Research:** …withdrew from this contract since Leishear Engineering could not provide a payment plan, which in turn was caused by NETL's refusal to provide any payment information. The sequence of emails documents this opinion.

On 12/4/2018, I sent an email to NETL, stating "I am writing an unsolicited proposal for a NETL research grant. To do so, I need to understand how I receive payments so that my subcontractors and I know what type of investments are required. …. Getting paid for these expenses in a timely fashion is important. Payment decisions are important to the success of this project." NETL's response was "Your questions are premature since most unsolicited proposals are not funded…".

That is, DOE refused to provide payment information since a contract award was improbable.

Then on 2/13/2019, the … withdrew from the contract after being informed that "DOE funding is assumed to be paid 30 days after invoice for labor and on demand for parts, but DOE will not confirm this assumption until after contract award". Specific statements were "… policy precludes bidding or accepting any Order that is not confirmed credit worthy, which from the below and our own due diligence prevents our participation with Leishear at this time".

As a confirmation and further investigation into this lack of knowledge about payment procedures, I contacted the Idaho Operations Office on March 14, 2019. I sent that email to DOE, stating, "With respect to purchases, can I order equipment, receive the final cost estimate, invoice DOE, get paid by DOE, and then pay the vendors to have purchased items shipped? I am considering research that includes high capital costs, and funding is important to the scope of my research proposal. If I must pay the vendors before DOE reimbursement, bank loans would be required, which significantly hiders this research. Thank you". In a very thoughtful response from Andrew Ford of DOE (dated 3/18/2019), Mr. Ford stated that "The guiding principles for awards are contained in 2 CFR 200 and 2CFR 910. As you can see highlighted below, the preferred method of payment to for-profit entities is reimbursement. From the 2CFR 200 it appears in certain scenarios advances may be possible. It would appear like the scenario you described may be possible based on the guidelines cited below. Sorry I can't be more direct in my answer as this is not a very common situation".

In other words, DOE could not explicitly state how payments would be made for time and materials. Bidding such a contract became impossible due to DOE's inability to answer questions on how payments would be provided for this research proposal. The inability of DOE to answer a simple question about how they pay contractors constitutes nonfeasance, which is failure to act; especially a failure to do what ought to be done.

Experimental research was then impossible due to funding uncertainties. A change in scope was mandatory due to the DOE inability to provide payment information.

6.0) **Project Scope Change Due to DOE Nonfeasance:** Changes were made to the project scope as discussed in Appendix C, p. 51. The same types of computer models were planned, but some models would be used as validation of explosion physics and nuclear reactor operations, since experimental explosion results would be unavailable for that purpose due to DOE nonfeasance.

7.0) **Project Intent Remained Unchanged:** The intent of this research has not changed at all since project inception. Since the cause of explosions has been proven, additional research is needed to understand how to stop explosions and to provide specific recommendations for the preventive actions that will stop explosions. The intent has not changed as exemplified by the following excerpts from the original Abstract and the Final Abstract that were submitted with the FOA Grant Proposal.

Original Grant Proposal Abstract: Explosive new technology has been invented to understand the explosions following the Fukushima Daiichi reactor meltdowns, a 705 pound hydrogen fire following the Three Mile Island (TMI) meltdown, and gas accumulation events that crack pipes in nuclear power plants. Using the same research results, corrective actions will be determined to minimize 250,000 North American piping failures per year. . …. To perform this research, the processes leading to explosions require computer aided models to fully understand accidents. …. Perform computer simulations of the Three Mile Island meltdown accident, with the first ever model of the hydrogen fire …. Damages to DOE facility piping will be prevented, in addition to the prevention of nuclear reactor fires and explosions …. Nuclear reactor building explosions can be stopped during unlikely meltdown accidents! Ongoing nuclear reactor piping explosions can be stopped!"

Final Grant Proposal 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. …. 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 …. Damages to DOE facility piping will be prevented, in addition to the prevention of nuclear reactor fires and explosions …. 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. …. 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."

8.0) **Grant Proposal Submittal:** A month was invested to write a detailed and comprehensive proposal to stop nuclear power plant explosions. This proposal was submitted to DOE in September 2019. The funding announcement number and title were DE-FOA-0001817, "U.S., Industry Opportunities for Advanced Nuclear Technology Development", and the Proposal number and title were was Application ARD 20.2-21608, "The Autoignition of Nuclear Power Plant Explosions". To be more concise, this title was revised from the original title of "Thermal Fluid Transients Cause Piping Failures and Nuclear Power Plant Fires and Explosions" (Appendix B, p. 45).

9.0) **Grant Dismissal / FOA Compliance Approval Reneged:** In a series of emails to the DOE Idaho Office (… - DOE representative), DOE dismissed the previously approved grant proposal without a complete evaluation, claiming that "your application does not meet the objectives in Section I B of the FOA, as it proposes basic research on explosion dynamics, work that would neither address challenges to advanced reactor deployment nor improve existing fleet performance. A merit review of your application will not be conducted per standard procurement protocols. …. Based on the limited information available in that abstract, this work appeared to be potentially consistent with the goals of the U.S. Industry Opportunities for Advanced nuclear Technology Development Financial Opportunity Announcement (FOA), but the Department of Energy, Office of Nuclear Energy (DOE-NE), reached a different conclusion based on the contents of the full proposal".

As discussed in Sections 3.0 and 7.0, this work certainly complies with the FOA requirements, and this DOE statement to the contrary is entirely false. In particular, DOE claimed that "Based on the limited information available in that abstract, this work appeared to be potentially consistent with the goals", but the DOE "reached a different conclusion based on the contents of the full proposal." is completely false since the goals and intent of this research to save lives did not change at all since this FOA was initially approved until the time that this research was disapproved. The intent of this research is identical when considering the original approved Abstract content as compared to the Final dismissed Abstract content. The goals / intent for both documents are shown to be identical above in Section (7.0).

10.0) **DOE Malfeasance and Cover Up:** The primary difference between the originally submitted Abstract and the final proposal were examples, or accusations, of NRC malfeasance, where a draft of Appendix A (p. 9) was included in the Grant Proposal. Appendix A ("Nuclear Power Plants are Not So Safe: A Question of Ethics", R. Leishear, Accepted for publication, in review) provides a technical account of NRC malfeasance with detailed examples, and Appendix A also provides a detailed prediction of the next nuclear accident in 2039. DOE thwarting of this research thwarts further exposure of an NRC cover up, and makes DOE complicit in that cover up. Persistent emails to DOE failed to garner any explanation or justification of these false comments that blocked this research. The DOE cover up is comprised of DOE stonewalling to obtain this information and the DOE refusal to fund this grant that will stop explosions.

Since this research grant can prevent loss of life, DOE inaction constitutes malfeasance and demonstrates that an active cover up of incompetent decisions is in process. That is, the proof of DOE malfeasance and proof of a DOE cover up to thwart this research is apparent in DOE false statements during the Grant Dismissal process and the DOE refusals to answer follow up emails that asked the same question over and over on May 5, May 8, and May 11. The specific unanswered question to explain DOE inaction and supporting allegations follow.

"To: DOE (…- DOE representative) and the Office of the DOE Secretary of Energy (…– DOE representative)

Please answer the question of why the prevention of nuclear power plant explosions does not "propose innovative technology development to improve the capability of the existing fleet". I have asked this question several times and the basic answer has repeatedly been that it does not comply because it does not comply. My extraordinary effort to save lives merits an answer. Details of my questions follow.

The DOE statement that preventing nuclear power plant explosions does not "propose innovative technology development to improve the capability of the existing fleet" is patently false. New research to prevent explosions certainly increases the fleet capability, and this research has the added benefits of preventing fatalities and environmental disaster. Allowing the next Fukushima type explosion to occur will severely damage the nuclear industry. TMI-2 and Hamaoka accident investigations were selected as well documented accidents to clearly understand nuclear power plant explosions and provide competent recommendations to ensure nuclear reactor safety throughout the fleet. This DOE decision to stand in the way of this research promotes such explosions, since the safety analyses of the U.S. reactor fleet are dangerously in error. Again, DOE may not care if previous NRC reports misrepresented the facts, and DOE may not care about loss of life, reactor damages, and damage to the environment due to explosions, but I do. This DOE decision is not in the best interest of our country - in fact this decision will ultimately hurt our country, since explosions like those in the photos below are expected in the US.

Also, DOE now claims that a previous evaluation has no value. Specifically, DOE stated in an earlier email that "After carefully studying the proposed concept, DOE has determined that the proposal fits under ... FOA No. DE-FOA-0001817". Granted, the scope has changed, but the intent to investigate power plant explosions remains unchanged, and the computer models to perform this research remain the same. DOE has changed their opinion on this research, but stating that the intent of this research has changed is completely false. The recent dismissal (attached) was based on the fact that this proposal includes explosion dynamics. For DOE employees to not realize that explosions were involved in the earlier Abstract could not have been true, given that the title was "Thermal Fluid Transients Cause Piping Failures and Nuclear Power Plant Fires and Explosions. Consequently spinning the facts to falsely indicate a change in the intent of this research is manipulative, albeit very well written. Although the DOE presentation is convincing, the underlying facts are false.

While there are technical differences in project scope, the primary differences between the initial Abstract and the final Proposal is the inclusion of specific safety issues and false accident reports by the NRC. Actively preventing this research could protect previous false government reports. I do not know why this Proposal was dismissed, but the as-written Dismissal does not agree with the facts. More importantly, the Proposal meets the requirements of the FOA and will prevent explosions and deaths. How can this work not be important to the DOE?"

To not fund this grant can result in loss of life during the explosion of a nuclear power plant that is predicted before 2039, where radioactive dust can be fired into the air and spread across the U.S. countryside to contaminate our homes and businesses with highly radioactive dust, which may result in mass evacuations. The stakes are too high for DOE to not investigate this serious safety concern through this research grant. For DOE to dismiss this research without any evaluation is nearly criminal. When an explosion occurs, and DOE has failed to act, perhaps there will be prosecution for criminal neglect, since people may be killed as a result of reactor power plant explosions. Again, explosions can be stopped, but research is needed to concisely determine preventive actions to stop future explosions, and this research grant will investigate required actions to prevent nuclear power plant explosions.

11.0) **Fraud, Waste and Abuse due to Mismanagement:** The falsification of facts by DOE constitutes fraud as defined by Merriam-Webster as “intentional perversion of truth in order to induce another to part with something of value or to surrender a legal right”. Loss of this contract to Leishear Engineering, LLC due to false claims by DOE certainly constitutes something of value.

The deliberate DOE prevention of this research grant constitutes waste since nuclear reactor piping is continuously damaged by small explosions that have incorrectly been reported as water hammer by the NRC since the 1950s (Robert A. Leishear, 2020, “The Autoignition of Nuclear Power Plant Explosions”, Journal of Nuclear Engineering Radiation Science and Technology, American Society of Mechanical Engineers, N.Y., N.Y.). More importantly, the imminent nuclear power plant explosion can have extraordinary financial and environmental costs to the U.S. economy.

All DOE correspondence were referred to a “technical team” for consideration, as stated by DOE representative Joanne Hanner. This technical team therefore represents management, and may even include managers, where their identities were shielded during correspondence. The joint efforts of this management team to misrepresent the facts as discussed above constituted abuse of their authority to execute contracts and fairly serve contractors.

12.0) **Grant Request:** This research grant request clearly meets the requirements of the FOA, and this research warrants DOE support to prevent fatalities and environmental disasters to improve the capability of the existing U.S. nuclear reactor fleet. The DOE refusal to support this research violates the FOA and can kill people.

13.0) **Please Expedite this Request:** A delayed investigation may serve to continue this DOE cover by preventing potential grant approval to proceed with this essential safety class research. That is, a lack of funding can be cited as an excuse for a DOE lack of action. Such an unethical sequence of events may appear to be equitable, when in fact such actions would not be competent, fair, or in the interest of nuclear reactor safety and public safety.

CONCLUSIONS

In closing, the DOE refusal of this grant to prevent these explosions constitutes waste, fraud and abuse. The importance and need for this grant are based on full time voluntary research that has been performed during the past four years to make our country a safer place to live. Previous research conclusively proved that fluid transients are the common cause of nearly all nuclear plant explosions – large and small, and these explosions are a major threat to health, safety, and the environment. Proposed research investigates methods to stop these explosions. The following conclusions support this statement.

Waste

- An imminent nuclear power plant meltdown is expected before 2039, and there is a one in two probability of an explosion at that time for the worldwide reactor fleet and an 11% probability of an explosion in the U.S. fleet.
- This explosion may be similar to the Fukushima explosions that killed people due to evacuations and spread a dust cloud of radioactive contamination across the planet.
- The proposed research will prevent ongoing small piping explosions during routine operations and future large nuclear power plant explosions during accident conditions.
- Proposed research will prevent significant waste of government funds.

Fraud and Abuse

- Using false statements and false claims, the DOE refused to fund this research as part of a cover up of explosion dangers to the U.S. reactor fleet.
- Joint efforts by a DOE technical team to falsify formal responses to dismiss a Grant Proposal (ARD 20.2-21608) without due cause constituted abuse of authority by the technical team.
- DOE actions constituted waste, fraud and abuse due to mismanagement of DOE programs.

Funding for this research is encouraged and requested. This unethically dismissed grant request should be reconsidered to prevent death and destruction. In short, nuclear power plant explosions of paramount importance can be stopped!

APPENDIX A

NERS-19-1132

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

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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 model reality, but facts are the true measure to describe reality. A question of ethics arises when facts are replaced with opinion to yield misleading and incorrect conclusions with respect to nuclear reactor safety. To continue the use of previous errant publications without acknowledging this dilemma represents a breach of ethics.

The major findings considered by this study follow, and calculations were performed with a 95% confidence level[1].

1. Explosions accompany nuclear power plant meltdowns.
2. A meltdown similar to Three Mile Island (TMI-2) has a 50% probability before 2039, with a one in two probability of a large radioactive release like Fukushima due to a meltdown, or core damage accident.
3. Nearly all predicted radioactive releases can be prevented.
4. A radioactive release like Chernobyl is expected between 2036 and 2067.
5. This predicted radioactive release can be delayed to occur between 2025 and 2090, or later.
6. Nuclear power plant accidental deaths are not significantly less 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
DOE	U.S. Department of Energy
GWe	gigawatt, electric
IAEA	International Atomic Energy Agency
ICRP	International Committee on Radiological Protection
IRPS	International Radiological Protection School
NEA	Nuclear Energy agency, OECD
NRC	U.S. Nuclear Regulatory Commission
LRF	large release frequency
MD	management directive
MWe	megawatt, electric
OECD	Organization for Economic Development and Cooperation
PSA	probabilistic risk assessment
R	Pearson function
RCWS	reactor coolant water system
S_y	Standard Error of Regression
TMI	Three Mile Island
WHO	World Health Organization
U	uncertainty

[1] Items 2, 4, 5, and 6 represent new research published here for the first time. Items 1 and 3 were published earlier but are discussed as proof of principle for the new research.

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, ethics.

INTRODUCTION

The primary goal of this original research is to improve nuclear power plant safety by convincing others that the next nuclear power plant explosion is imminent and that nuclear power plants are as safe as other industries, although not as safe as previously thought. New explosion predictions are the crux of this research, and corollary ethical considerations are secondary, but extremely important with respect to how earlier conclusions with respect to rector safety were reached. The questions of ethics presented here are not accusations of wrong-doing, but observations that principals of ethics have been violated by omission. In efforts to do well, the facts are sometimes side-stepped. As a matter of fact, this paper drastically changed through different revisions as this author's sense of ethics evolved with respect to very complex issues of concern. Guilt or blame is not the issue - the issue is that reactor safety conclusions are unethically, and therefore incorrectly, presented and addressed in the nuclear industry. Reactor safety and explosion predictions are the paramount issues considered here.

By considering the history of nuclear power plant accidents, predictions of future accidents and explosions can be statistically determined. The most important of these findings is that the next meltdown is expected before 2039, and that there is a one in two probability of a large scale radioactive release to the air and across the globe during that event. To predict future nuclear accidents and explosions, in-service nuclear power plant accidents must be considered.

For nuclear power industry explosions there are also two primary ethics issues that are considered, which are intertwined with nuclear power plant safety. The first ethics concern is related to the Three Mile Island nuclear reactor meltdown, where pertinent technical data was excluded from investigation reports. Specific evidence to prove that an explosion occurred at TMI-2 has been available in U.S. government reports since 1979, that evidence has been ignored in support of an opinion that a fire occurred at TMI-2 (Leishear [1 and 2]), and that previous evidence is challenged here. In fact, the intentional oversight of facts which prove that explosions occurred at TMI-2 has prevented the understanding of nuclear power plant explosions for decades.

The second ethics concern is related to probability theory that was used in earlier research by others to incorrectly evaluate and misrepresent the safety of nuclear power plants, and this study works to use that same probability theory to prove that reactor safety is improperly presented in previous literature[2]. First of all, graphic

[2] The claims made in this paper challenge long-held beliefs of engineers, scientists, regulators, and plant operators throughout the nuclear industry since the 1950s, and accordingly the credentials of the author are of paramount importance to forge this research. Ordinarily, this much detail on an author's background is not presented in a paper, but the stakes are high, and credentials are extremely important to the success of this research. To pursue this nuclear power plant explosions research, this author has spent four of the past five years performing full time voluntary research – at a personal cost of more than $130,000 - to prove the technical conclusions that are presented in this paper. To document this research, he wrote 12 peer reviewed publications on nuclear power plant explosions. To prove these publications, the author's research included completion of all of the courses required for a Ph.D. in Nuclear Engineering in addition to his previous Ph.D. in Mechanical Engineering at the University of South Carolina. He also completed many other supporting courses for the specific purpose of investigating nuclear power plant explosions. These courses included 8 combustion courses taught by the Combustion Institute at Princeton University and by CEFACS from Paris; 18 finite element courses for combustion, explosions, fluids, and structures that were taught by Fluent/Ansys/Autodyne; 9 nuclear reactor design courses that were taught by the U. of Barcelona, the U. of Illinois, the Organization of Economic Cooperation and Development (OECD) in Paris, Oak Ridge National Laboratory, and the US NRC; 7 corrosion courses taught by the National Association of Corrosion Engineers; an International Nuclear Engineering Law course taught by the OECD at the U. of Singapore; and an International Radiological Protection School (IRPS) course taught by the OECD at the U. of Stockholm.

Prior to this research, the author wrote a book for the American Society of Mechanical Engineers on the topic of piping failures that discussed nuclear power plant explosions, while he worked as a Research Engineer / Principal Investigator for Savannah River National Laboratory (SRNL). Many of the author's credentials were specifically tailored to this research. Since this research is hinged on statistical analysis, the author's credentials in that field 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 appropriate instead of frequencies, and risk evaluations prove that previous publications are faulty and misleading. The following discussion supports these opinions, which will be controversial to some engineers, scientists and politicians, and care is therefore taken here to competently prove these opinions. The issue of ethics is seldom discussed with respect to engineering publications, and this issue deserves attention. After all, safety is paramount.

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 the prevention of major accidents can drastically improve safety in the nuclear industry (Leishear [1]). 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 resultant accidental deaths primarily bound this study.

This paper is part autobiography, part philosophy, and part engineering fact, making this paper unique with respect to presentation and results. Bringing together these parts forms a coherent discussion to prove that nuclear power plants are not as safe as previously believed, and that their safety can be vastly improved. Numerous topics support research conclusions, and a summary of nuclear accidents is first required to introduce accident frequencies, accident risks, probabilistic safety analysis (PSA), statistical models, and ethics.

NCULEAR POWER PLANT EXPLOSIONS

Nuclear power plant explosions are central to this study. Three of the primary accidents of concern to this study merit 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 [1][3]). 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 involved the only reactor of these three accidents to experience a criticality, which is a major release of energy during uncontrolled nuclear fission. These accidents are described in detail in a series of papers (Leishear [3-7]), where this paper is essentially one more paper in a series of papers that present ongoing explosions research. With respect to quality assurance, excellence is the target of this research, since excellence is an accident if the target is mediocrity. These papers are part of an intricate series of 14 peer reviewed papers series that prove a well detailed and comprehensive case that the cause of all nuclear power plant explosions, except Chernobyl, were the direct result of pump and valve operations (The Leishear Explosion Theory: Fluid transients ignite explosions). This paper represents the turning point between proof of theory and the prevention of future nuclear power plant explosions, which include hundreds of ongoing small explosions and large explosions like those that occurred at Fukushima and Three Mile Island.
    a. The TMI-2 accident had multiple contributing causes, e.g., an inadequate safety analysis, inadequate lessons learned processes since a similar accident was successfully averted at the Davis-Besse nuclear power plant, inadequate operator training where the operators responded in accordance with U.S. Navy

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deserve mention. He worked as a Fellow Research Engineer, or Principal Investigator for SRNL, using statistical analysis to document experimental research, and he was qualified / certified as a Metrologist by the National Voluntary Accreditation Program, where one his duties was to perform statistical uncertainty analysis to calibrate nuclear process instrumentation, using the Guide to Uncertainty Measurements. He worked as a Shift Technical Engineer, and his responsibilities were the application of Safety Analysis to operational and emergency operations, where he trained full time for a year to pass the Oral Board Examination to secure this position. As part of his Ph.D. course work, he also studied risk analysis for nuclear reactor systems.

Moreover, the intensive volunteer study over the past years has been paralleled by few, if any, other engineers, where this extensive and exhaustive research was performed for the sole purpose of proving the common cause for nuclear power plant explosions.

Not only did the author invest extraordinary efforts to support this research, but his wife, Janet Leishear, sacrificed much over many years to support this research, a reviewer for all publications and unbelievable day to day support to ensure that this research continued.

[3] This section on Primary Accident Descriptions is paraphrased from an earlier reference (Leishear [1]). Other accidents could also be described in detail, but these three accidents provide an overview of accident complexities and similarities.

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 later developed to provide full-time technical support during all operations. In spite of difficulties, operators brought the accident under control before a complete meltdown occurred where the fact that a partial 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 control 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 engineering tests on reactor operations, and incompetent management and engineering decisions that were performed to bypass safety interlocks. 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, and explosions occurred in Units 1 through 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 through the interactions of radiation with water. 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 in the dieseling process, similar to a diesel engine. When this autoignition temperature / pressure is achieved, hydrogen explodes when 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 that were separated by seconds. The first explosion was due to the autoignition of hydrogen and oxygen that were generated by thermolysis and radiolysis, which were generated by a criticality. When this first explosion ruptured the reactor vessel - that was not designed for high pressure containment - a large volume of hydrogen mixed with the 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 calculated to be equivalent to 14 metric tons 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 that damaged the fuel rods in the core, and this initial explosion was did not breach the reactor like Fukushima thermolytic explosions since the TMI-2 core was only partially melted and Fukushima cores are believed to have completely melted. As the TMI-2 coolant pumps were started, a large volume of Zircalloy corrosion generated hydrogen that was released to the reactor containment building. As the pumps continued to operate two different explosions occurred, but both the second and third explosion were caused by thermal-fluid transients – gas was heated by compression and exhausted to burn explosive gases. The second explosion created an open path to the containment building by bursting a rupture disc in preparation for the next explosion. The third explosion autoignited the reactor containment building hydrogen that had mixed with air[4]. In fact, a safety valve on the reactor coolant system (RCWS) opened at the same time as this last explosion, which was incorrectly considered to be a fire for the past forty years (Leishear [1 and 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.
g. Additionally, using high frequency transducers to monitor RCWS pressures due to small explosions will provide insights into the many small explosions that continue to occur in reactor systems worldwide and in the US.

A DISCUSSION OF ETHICS[5] WITH RESPECT TO PAST ACCIDENTS

A different technological perspective – ethics - is presented here that establishes a threatening danger to the public. Goals of this paper with respect to ethics are to consider the ethical implications of new research, to question the ethics and use of previous publications by others, and to question the ethics of government organizations.

Poor ethical decisions that engineers make, either intentionally or by rationalization, are the reason that ethics discussions are included in this paper. To prevent future meltdowns and explosions engineers must not only consider technology, but must consider the ethical process of how they make decisions. Some previous decisions may have been made in the absence of the new explosion theory that is presented here, but explosions research and nuclear reactor safety were thwarted by the fact that essential information has been misrepresented and eliminated from safety evaluations. The practice of ethical engineering decisions is essential to nuclear safety.

With respect to ethics, one question is whether or not the ethics of previous research should be questioned at all. After all, a primary tenet of engineering publications is that authors do not directly confront one another on questions of ethics. A common refrain is that we agree to disagree. This approach minimizes potential animosity between researchers for the higher purpose of advancing technology. However, part of this research is based on previous works that misrepresent the facts by neglecting conventional wisdom that was available at the time of publications.

If the facts are misrepresented, how can that work be ethical? For this author to not challenge the ethics of incorrectly promoted research would be unethical. In other words, a different view of nuclear technology challenges the status of ethics. That is, engineers are responsible to identify ethical concerns, and to take action to address those concerns. This publication challenges previous ethical decisions to advance technology and nuclear safety. Simply publishing technical information for others to decide what is right or wrong falls far short of engineering excellence, integrity, honesty, and ethical conduct.

One may argue that ethics is not the issue at all for previous papers, and that the publication problems identified in this paper are the simple progression of technical knowledge. This author disagrees since the appropriate knowledge was available at the time of those publications, and that knowledge was not used. One may argue that the scientific community and society itself will ultimately judge which, if anything is correct, but this opinion is fundamentally flawed in that the free exchange of ideas about ethics is essential to improve research publications. Why engineers make decisions is as important as the decisions themselves, since engineers are the stewards of nuclear safety and the lives of our neighbors. One may also disagree with this work, and ethics would not be a problem at all, but this paper proceeds as if the work presented here is correct, since remarkable efforts have been

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[4] There may have been other small explosions inside the TMI-2 reactor system, but these three explosions are the most important with respect to the explosion in the reactor containment building.

[5] An IRPS course sparked this paper. Topics from different instructors included ethics in the radiological protection industry and safety in that industry. This author questioned the ethics and validity of using past publications to establish safety in the nuclear reactor industry. The instructor's response was that the use of consequence instead of risk leveled the playing field, but this author believed that response to be unethical since data was improperly manipulated in those publications. That single, original question was the start of the technical research needed to bring this paper to fruition. Additionally this TMI-2 discussion was not included in the first draft of this paper. Even though the title of this paper concerned ethics, a direct confrontation with the NRC was not initially pursued. This dilute version of an ethics discussion prompted reviewers to comment that there did not appear to be an ethics issue at all and that the ethics issue was not adequately proven. The NRC is the primary stakeholder to ultimately correct these problems, and an affront to their authority is not the smoothest way to gain their cooperation, but a more amiable approach has failed to yield NRC action and cooperation for years.

taken to ensure that this work is correct. Accordingly, ethics issues are identified in cases where the information was at hand for others to perform better research that did not skew data to yield inappropriate and unsafe conclusions.

Accordingly, specific research conclusions that are unethical need to be identified before an overarching discussion of ethics can be presented, since new research is intertwined with the ethical conclusions of previous research. The new research interests are the facts that explosions occur during all nuclear power plant meltdown accidents, and explosions also occur during routine operations of nuclear power plants (Leishear [1]). Even so, discussions of these recent discoveries by themselves do not raise ethical concerns, where fluid transients have been identified to be a common cause of most explosions in nuclear power plants. Transient pressures due to pump and valve operations compress flammable gases in nuclear reactor systems to cause autoignition and explosions in nuclear power plants.

As discussed in detail below, this discovery was hindered by previous government reports that intentionally disregarded data, which proved that an explosion occurred at TMI-2, where these actions were unethical. New research has been further hindered by government organizations such as the NRC and the U.S. Department of Energy (DOE). Essentially, the U.S. government has hindered explosions research for forty years and continues to do so. This challenge to the government will hopefully turn their direction to accept the fact that nuclear power plant explosions can be stopped and that actions need to be taken, where their lack of action is a continuing ethical concern as discussed below.

FALSE REPORTING OF TMI-2 EXPLOSIONS

False reporting raises ethics concerns, and specific incidents of false reporting follow. Immediately following the 1979 TMI-2 reactor core meltdown, there was great fear of an explosion of large hydrogen bubble in the reactor building after the meltdown, as expressed by the Governor of Pennsylvania and others as reported by the press. Nobody knew that explosions had already burned the hydrogen in the reactor containment building. In a subsequent U.S. Nuclear Regulatory Commission (NRC) report (Henrie and Postma [8]), a conclusion was stated that there was not an explosion during the accident, and nobody knew that there was an explosion prior to this contemporary research.

Were politics the driver behind the intentional suppression of 1979 TMI-2 data that proved explosions had already occurred? Regardless, the TMI-2 accident had a devastating effect on nuclear power plant production and resulted in remarkable safety improvements to the reactor fleet.

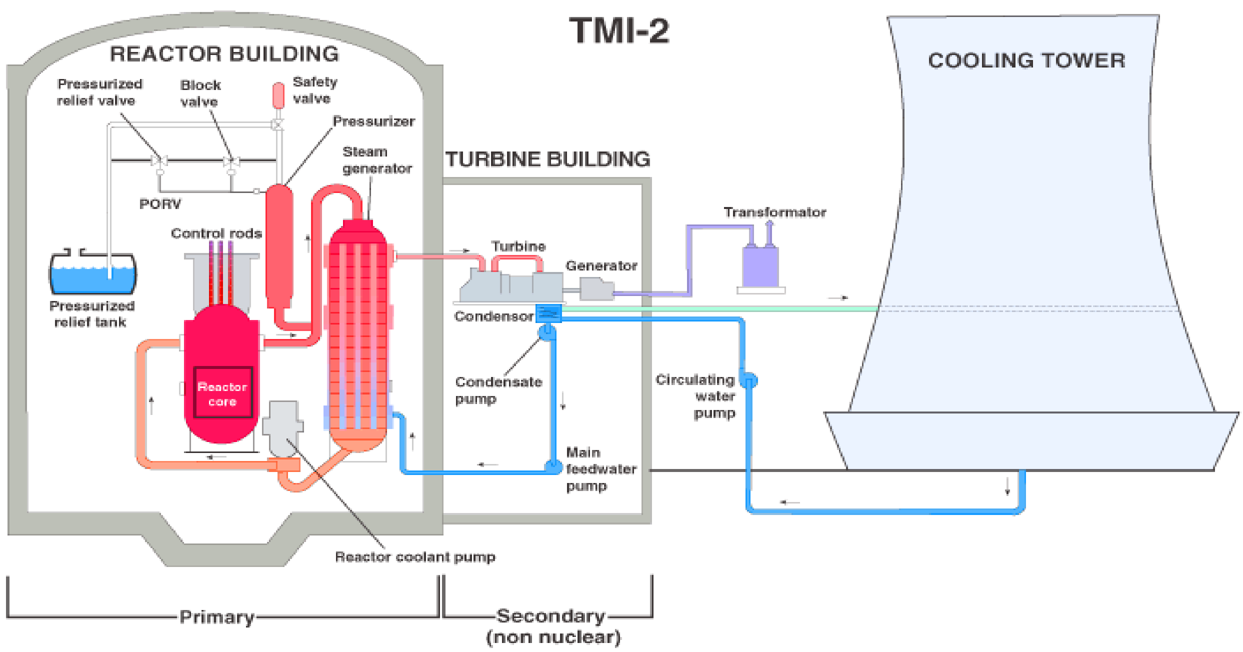

Figure 1: TMI-2 Configuration (U.S. NRC)

TMI-2 Explosions Data

Discovered during this ongoing research, three facts were intentionally omitted from the original TMI-2 accident analysis. First and most importantly, an explosion was measured during this accident and reported in an NRC report, where two reactor building pressures were measured during the accident. The first pressure peak went off the scale, and the second pressure peak was consistent with the occurrence of a fire. The explosion pressure was then discarded by the accident investigators, and the lower pressure was used to perform complex calculations to falsely prove that only a fire occurred. All subsequent NRC accident descriptions failed to mention the observed explosion pressure, and referred only to the pressure that supported a false conclusion that a fire rather than an explosion occurred during the TMI-2 accident.

Second, the accident investigators reported that temperature indicators, or thermocouples, documented the path of a fire through the TMI-2 reactor containment building. Thermocouples were reported to collect data every 15 seconds, which lent great credibility to the temperature data to prove that a fire occurred. However, the 15 second interval was associated with a complete set of thermocouples spread throughout the building. Discrete thermocouples actually reported data every two minutes, which entirely discredits the temperature reporting since a reading every two minutes provides negligible data to track a high velocity explosion wave. Consequently, the use of thermocouples to prove that a fire occurred is discredited.

Third, there were three explosions during the TMI-2 accident – this theory is a recent addition to the engineering literature (Leishear [1]). The first explosion occurred inside the reactor at the time of meltdown, and the operators did not know that there was meltdown in process. The second explosion occurred while refilling the reactor system with coolant water – the accident was caused by accidentally dumping the cooling water from the reactor, which caused half of the nuclear fuel inside the nuclear reactor to melt. This second explosion occurred inside the piping that connected the reactor to the reactor containment building. When this explosion occurred, the water in the pressurized relief tank (shown in Fig. 1), was blown out of the tank through a rupture disc that burst open during this explosion. A level indicator showed that the tank was in fact empty after the accident, which of course assisted in the proof of an explosion, However, the final NRC reports concluded that the tank could not be empty since there was no explosion, and the NRC therefore concluded that the instrumentation did not work properly - there was no validation of whether or not the gauge worked. That is, more crucial evidence was discarded, which supported a conclusion that an explosion rather than a fire occurred. Then, hydrogen from the melting core was dumped from the RCWS safety valve, into the connecting piping, through the rupture disc, and into the building – an explosion was waiting to happen. A subsequent explosion occurred in the reactor building, which was falsely reported as a fire for 40 years, and a recent publication clarifies this mistake (Leishear [1]).

Now to the question, were the TMI-2 reports unethical? The answer is unequivocally, yes. Although the intent to perform technically competent work is partially evident in the detailed report calculations, the end result of the selective choice of evidence represents a breach of ethics that yielded false conclusions. All data was discarded if that data did not conclude that a fire rather than an explosion occurred. Experimental data was selectively considered to prove a specific and false conclusion. Was data deleted to cover up an explosion as part of a political agenda to promote rector safety? Probably, but a 1979 cover up cannot now be conclusively proven. All that can be proved at this late date is that pertinent data was intentionally omitted from final reports, and that a TMI-2 cover up continues. A fire did not occur at TMI-2 - explosions occurred at TMI-2. These misleading conclusions prevented this explosion discovery for many years.

Recent History of TMI-2 Explosions Research

Since 2011, this author has conducted a series of discussions with the NRC to stop nuclear power plant explosions through this ongoing voluntary research. Initial concerns expressed to the NRC were summarily dismissed. Persistent communications with the NRC resulted in the assignment of a NRC engineer to address nuclear reactor safety concerns. In an effort to prove that safety concerns were incorrect, he provided a copy of Henrie and Postma's report [8].

That report provided sufficient information to prove that the so-called fire at TMI-2 was caused by the opening of a safety valve to autoignite the reactor building hydrogen fire, where 705 pounds of hydrogen was inadvertently dumped to the reactor containment building. Hydrogen then burned until sufficient oxygen to support combustion was depleted.

In accordance with this NRC report, this author incorrectly believed that a fire occurred at TMI-2, and published an ASME Mechanical Engineering Magazine article on the TMI-2 hydrogen fire (Leishear [9]). This magazine article was then incorrectly used as a technical background to address the TMI-2 fire concern and explosion concerns during other accidents, such as Fukushima. Since the original TMI-2 report stated that there was a fire, this author believed that there was a fire. The author then submitted a request for the NRC to further investigate fires and explosions, based on this article. In other words, the NRC provided technical information to counter the author's safety concerns (Leishear [10]), but that information further fueled an evolving explosion theory. A Generic Issue was submitted to the NRC for further consideration, and the NRC dismissed this safety concern, based on the 15 second intervals of temperature measurements, an empty pressurizer tank, and a stated lack of explosion data. As noted above these NRC opinions for dismissal were based on published false facts. The NRC acted ethically in good faith, but earlier ethical violations were fundamentally flawed, which resulted in the NRC rejection of a correct autoignition theory to explain the hydrogen burn at TMI-2.

Five years later, this author discovered that an explosion occurred rather than a fire (Leishear [1]). While performing the extensive research noted above, new facts were uncovered. A comparison of explosions at Chernobyl, Fukushima, and TMI-2 concluded that there were remarkable similarities between Fukushima and TMI-2. In fact, these two accidents had such significant similarities that explosions had to have occurred at TMI-2. An intensive study of the TMI-2 accident was then performed to uncover the fact that an explosion had occurred, but that applicable data was ignored during the NRC investigation to support a conclusion that a fire rather than an explosion occurred. In other words, new findings supported a conclusion that 1979 research was unethical since pertinent technical data was intentionally neglected. Even though the intent of this neglect by the NRC may not have been dishonest or malevolent, this neglect of facts during scientific investigations of reactor safety was certainly unethical. In response to these findings, the NRC was again contacted. Flawed NRC rebuttals and unanswered allegations demonstrate a pattern of NRC refusal to acknowledge a severe safety problem for the U.S. reactor fleet.

In other short, this author determined that there was a common cause for reactor fires and explosions, An NRC rebuttal provided the information to prove this work was competent. Pre-GI-015 was written to encourage the NRC to take action on hydrogen fires and explosions. The NRC rebutted that request. Further research proved that the rebuttal was incorrect n and proved that an explosion rather than a fire occurred at TMI-2. The only fires that occurred took place in buildings after the initial reactor system explosions occurred, similar to Fukushima.

Ethics and the NRC[6]

The following letters were written by R. A. Leishear to the NRC[7], and the NRC failure to respond to new information for safety challenges the ethics of the NRC nuclear power regulators[8]. Ignoring safety problems that affect the entire U.S. reactor fleet is, in itself, an unethical act by the NRC. A bureaucracy, in itself, cannot be attributed to be unethical, but the actions of its individual members results in unethical behaviors that affect the safety of the public by thwarting new technology. Specifically, the NRC did not comply with their procedures (MD 8.8 [11]), which state that the NRC shall comply with the following directives. Failure of the NRC to evaluate safety concerns when lives, property, and the environment are at stake constitutes malfeasance, where Merriam-Webster defines malfeasance as "wrongdoing, especially by a public official".

1. It is the policy of the U.S. Nuclear Regulatory Commission that allegations associated with NRC-regulated activities are properly documented, assigned for evaluation, assessed for safety significance, and evaluated in accordance with this management directive.
2. "Ensure that individuals making allegations are treated professionally, are encouraged to provide information, and receive timely feedback by way of correspondence, telephone discussions, and visits, as appropriate".
3. "Ensure that safety-significant allegations are promptly reviewed and take any actions necessary…"
4. "Ensure that allegations concerning NRC licensees, license or certificate applicants, or other affected organizations are reviewed…"

Since the NRC did not respond to the following emails, there is no evidence that any of the following safety significant and safety class issues were addressed with respect to nuclear power plant safety.

[6] The first draft of this paper did not include specific discussions of NEA, NRC, or DOE ethics violations. Consequently, several reviewers noted that there was either a lack of an ethics issue or a lack of specific detail to make claims about ethics. Affronting government authorities seemed problematic, and an ethics issue for this author was learned. Specific accusations are mandatory to prove ethics violations, and this author had to step up to make those accusations so that important issues of nuclear safety can be addressed and corrected. Accordingly, this paper may bring about important engineering discussions between engineers and regulators.

[7] Emails to the NRC are permanently stored on computer backups and the original copies of NRC and DOE emails are available through the Freedom of Information Act. NRC emails are supplied as-written from leishear@aol.com.

[8]The naming of specific government employees who were contacted is inappropriate for this work.

"The NRC Cover Up" (To: allegations@nrc.gov, 3/7/2019)

"Although I have written numerous unanswered emails to the NRC on nuclear power plant fires and explosions, I have realized that the NRC has intentionally neglected facts that resulted in a cover up of the 1979 Three Mile Island explosions. I published a series of 11 papers [14 papers now published] since 2011, where I believed that NRC reports were technically incorrect but competent. However, as I work toward the final phases of my research, I realized that Fukushima and Chernobyl each experienced explosions, and that Three Mile Island must have also experienced explosions due to accident similarities. Having reached this conclusion, I reevaluated other NRC reports, and I learned that NRC investigators ignored the facts that conclusively prove that there was a Three Mile Island explosion, rather than a fire. These findings are in review for publication [Findings are now published]. Perhaps the NRC will consider a response to this allegation, since many NRC documents are technically unsound, and false, as a result of this finding."

"Safety Concern – Hydrogen Autoignition" (To: allegations@nrc.gov, 10/12/2018)

"Current NRC regulations are apparently inadequate with respect to safe design requirements for the U.S. nuclear reactor fleet. This letter is the latest in a series of communications with the U.S. NRC. In fact, the NRC previously responded to safety concerns through "Auto-ignition of a Hydrogen-oxygen Mixture in the Reactor Coolant System, Memo - ML15191A397" [12]. Since that memo was released, numerous publications have refuted the NRC opinions presented in that memo. The attached article summarizes those new publications and demonstrates that regulations are incorrect.

… "Probabilistic risk assessment (PRA) applies the probability of failure for the components of a system to determine the overall failure probability of that system. According to the NRC (NRC [13]), the risk of a core accident, which includes meltdowns, should be less than once in ten thousand years (1/10,000 years), and the risk for a large radiation release to the public must be less than once in a hundred thousand years (1/100,000 years)." [More recent recommendations change the LRF to 1 in 1,000,000 years, (NRC [14])].

"Considering a PRA, the new theory presented here questions accident frequencies of the NRC with respect to this technology. That is, the research presented here shows that the probability of an explosion following a meltdown is 100% (1.0). Also, two out of three (2/3) of the accidents at Chernobyl, TMI, and Fukushima resulted in large releases of radioactive materials. Therefore, the probability for a large, random radiation release" approximately "equals 1.0 X (1/ 10,000 years) X (2/3) = 6.7 times in 100,000 years > 1/100,000 years."

Note that the probability of a radiation release exceeds the probability that is permitted by NRC regulations. Many U.S. reactors may be safely designed if the Operator used a lower frequency than required by the NRC in their Safety Analysis calculations, but the NRC regulations governing safety calculations appear to be incorrect".

"Inspector General Audit - Fires and Explosions in Nuclear Power Plants" (To: allegations@nrc.gov, 5/29/2018)

"I participated in an audit conducted by the Inspector General's Office, which concerned a request for a generic issue, i.e.., "PRE-GI-015, Hydrogen Fires and Explosions in Nuclear Reactors, ML15245A508 [10]. … Although the audit should be favorable to the NRC, the NRC response for this nuclear reactor safety issue was fundamentally flawed.

The auditors introduced the Audit by stating that they were interested in how the audit was conducted, rather than whether or not the audit was effective. The audit was very professional and addressed issues with respect to how Generic Issues are processed. The auditors considered my statements that the NRC response to this request was denied without further discussion. Consequently, I recommended that those who submit requests for Generic Issues be allowed to rebut the NRC response, which, of course, is not presently allowed. Otherwise, the audit met its limited scope.

Addressing this limited scope of the Inspector General Audit, I responded with the following comments.

1. The NRC response presented in ML15245A508 [10] was incorrect, and did not adequately address nuclear reactor safety concerns.
2. NRC regulations are currently incorrect, and allow Safety Analyses to be incorrectly written, which in turn potentially allows reactors to operate unsafely. Accordingly, all accident analyses for U.S. reactors are incorrectly performed.
3. Hundreds of small fires and explosions have occurred in U.S. nuclear power plant piping systems and will continue to occur, where these accidents have been misdiagnosed as water hammer accidents since the 1950's.
4. As an expert in water hammer, I am aware that the conditions the NRC attributes to piping water hammer damages actually reduce the water hammer induced pressures in the piping system. That is, trapped gas pockets in the system do not increase pressure surge magnitudes, they decrease the magnitudes of those pressure surges.

As a result, fatigue failures in piping continue, and they will progressively increase in frequency until this problem is addressed.

5. The NRC response to ML15245A508 [10] was well considered, but was incorrect, where I was not allowed to challenge the [incorrect] NRC conclusions.
6. As part of my ongoing research, I published five ASME Conference publications in 2017 to challenge the ML15245A508 NRC responses [10] and to clearly state the errors that were provided in the NRC conclusions.
7. In short, NRC regulations are incorrect, U.S. reactors are operating unsafely, and reactor system piping damages will continue unless corrective actions are taken.
8. The NRC has refused to even acknowledge these serious safety issues and cost concerns".

"Fires and Explosions in Nuclear Power Plants" (To: allegations@nrc.gov, 5/26/2018)

"The … paper, ANS 22950 [7] (supported by other referenced, 2018 technical publications) contradicts an NRC request for a Generic Issue, where I raised Safety Analysis concerns about the operations of U.S. commercial nuclear reactors. The NRC provided a formal response per PRE-GI-015, Hydrogen Fires and Explosions in Nuclear Reactors, ML15245A508 [10]. I disagreed with the NRC response at the time, and I have continued research since that time. There is no doubt that the hydrogen fire at Three Mile Island, the explosions at Fukushima Daiichi, and an explosion at Hamaoka were all caused by the detonation of hydrogen due to fluid transients. Pump and valve operation compressed hydrogen and oxygen to ignite these accidents. Not only were these accidents ignited by fluid transients, but gas accumulation event shave been incorrectly diagnosed since the 1950's. The current NRC position is that trapped gas compression causes piping damages. To the contrary, trapped gasses reduce water hammer pressure waves. The actual problem is that when pumps are started, the trapped hydrogen and oxygen from radiolysis compresses, autoignites, and explodes or burns depending on the amount of flammable gas present at the time of ignition. In other word, there have been hundreds of fires and explosions in nuclear reactor systems that have been misdiagnosed for many decades".

NRC Neglect of Safety Concerns

Neglect of safety concerns raised to the NRC certainly constitutes a breach of ethics[9]. According to an NRC Directive (NRC [11]), "It is the policy of the U.S. Nuclear Regulatory Commission that allegations associated with NRC-regulated activities are properly documented, assigned for evaluation, assessed for safety significance, and evaluated in accordance with this management directive (MD). In implementing this MD, responsible NRC staff will respond immediately to an allegation involving an overriding safety issue (An issue that may represent an actual or potential immediate, significant, or immediate and significant threat to public health, safety, or security, warranting timely action by the licensee to evaluate and address the issue.)". The NRC has not responded to any of these correspondences over the past two years, and the topics of these letters present a significant threat to public health and safety.

SAFETY OF THE EXISTING REACTOR FLEET

Having reviewed the technical aspects of nuclear power plant explosions, the relevance of these explosions to nuclear power plant safety can be discussed along with evaluations of previous publications. Plant safety is typically analyzed in terms of PSA, where one underlying assumption of previous and present PSA predictions is that the entire world-wide fleet of reactors can be grouped together for comparison. Flaws in previous PSA evaluations predict reactor operations to be safer than they are.

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 in the reactor fleet, and the results PSA prediction was ignored at that time. Consequently, PSA methods were validated by the TMI-2 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

[9] Numerous companies and agencies refused to acknowledge email correspondence about this research and the dangers of nuclear power plant explosions. They included Chubu Electric and its parent company Tokyo Electric Power Company, the IAEA, the NEA of the OECD, and the Nuclear Regulatory Agency of Japan (formerly the Nuclear and Industrial Safety Agency, which was disbanded since they promoted a policy that a Fukushima type accident was absolutely impossible).

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 currently 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 ≈450 operating reactors are Generation II designs. Generation III designs (Fig. 2) are presently under construction or planned for later construction, and Generation IV designs are future designs, which are not yet under construction. 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) European Nuclear Society [15]). The 2012 number of in-service Generation II and III reactors is shown in Fig. 2.

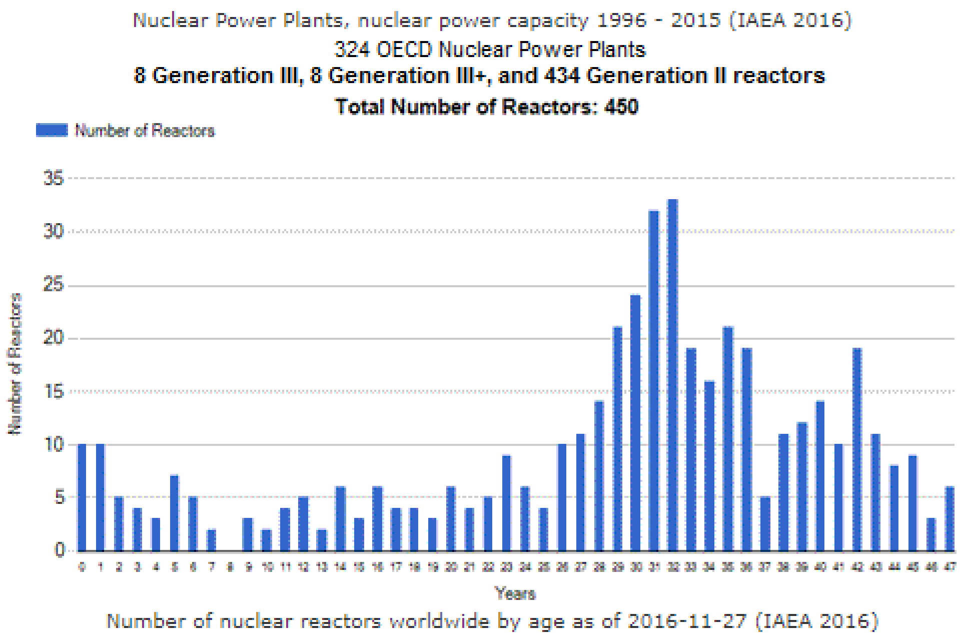

Figure 2: Operating Nuclear Reactors (Adapted by permission of the European Nuclear Society [15])

PSA applies probability and statistics to model the risks associated with accidents. PSA calculated risks equal the frequency times the consequence (Modarres, et al [16]), such that

Risk = The accident frequency multiplied times the consequence of the accident (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, or cumulative, frequencies or risks are associated with actual accident conditions that express real conditions, or historical trends for the entire fleet. In other words, PSA risks describe the potential for an accident to occur for any discrete reactor, and in-service risks describe the potential for an accident to occur anywhere in the world. Since a nuclear power plant explosion anywhere around the globe would be catastrophic, the in-service risks are the risks of primary concern to this study.

PSA, Reactor Design Accident Frequencies

As one factor of risk, frequencies are considered next. Important 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 CDFs and LRFs are compared in Figure 3 (NEA [17]), using an approximation that is affected by the age of the data, since the original plotted values are less than the CDF and LRF frequencies today due to safety modifications implemented after the TMI-2 and Fukushima accidents. This approximation is reasonable given the accuracy of other calculations in this work[10], where calculation accuracies vary depending on source material. Then, from Fig. 3 the average values for the CDFs or LRFs of Generation II reactors (most of the fleet as shown in Fig. 2) equal

$$PSA, Reactor\ design\ CDF\ (Average) = 8 \cdot 10^{-5} \text{ core damages / year} \tag{2}$$

$$PSA, Reactor\ design\ LRF\ (Average) = 2 \cdot 10^{-5} \text{ large releases / year} \tag{3}$$

PSA, Reactor Fleet Accident Frequencies

Since reactors operate independently, CDFs and LRFs are statistically independent probabilities. Consequently, the CDFs and LRFs for the reactor fleet do not equal any one of the specific frequencies or the average frequency plotted in Fig. 3. Probabilistically, the CDFs and LRFs equal the sum of their individual probabilities, such that

$$PSA, Fleet\ CDF\ = 450\ reactors \cdot 8 \cdot 10^{-5} \frac{accidents}{reactor \cdot years} = 3.6 \cdot 10^{-2} \frac{accidents}{year} \\ \rightarrow 27.8\ years\ until\ the\ next\ meltdown \tag{4}$$

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

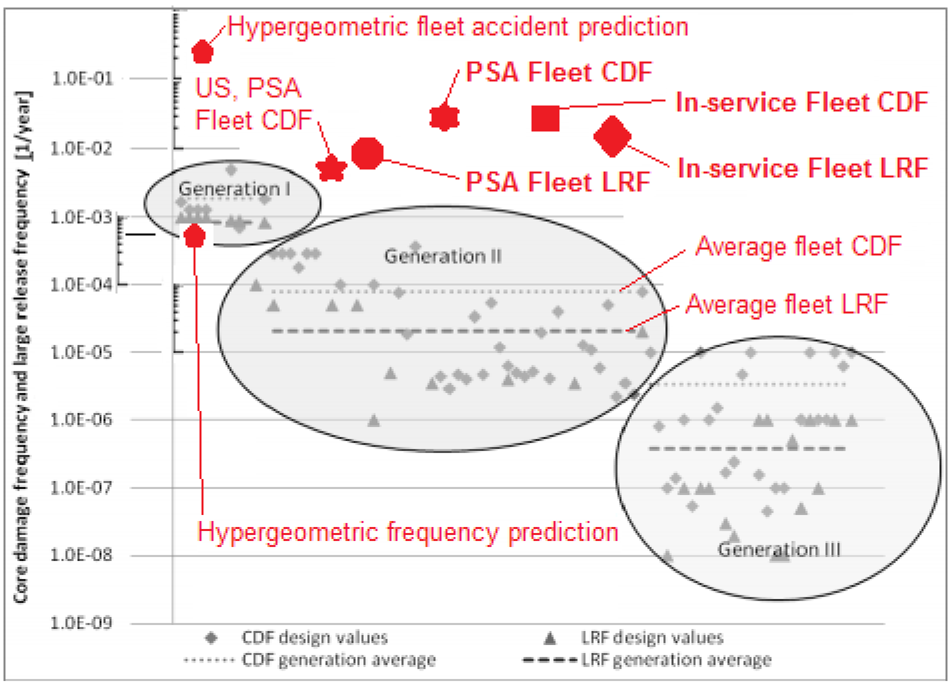

Figure 3: Generation II, Nuclear Reactor Core Damages (Meltdowns) and Large Radioactive Releases[11]
(Adapted from NEA [17][12])

[10] A detailed analysis for all of the uncertainties associated with all of the graphs in this paper is outside the scope of this work. Even so, published graphs by others that are used in this paper are sufficient to perform this study.
[11] Revisions to this figure are new to the literature, and were previously neglected. Uncertainty analysis is preferred, but was not provided by the original authors.
[12] This figure is provided in the NEA document, but their references to the IAEA source document are incorrect.

These values are plotted in Fig. 3 as "PSA Fleet CDF and LRF". Note that the PSA fleet frequency significantly exceeds the average reactor design values shown in Fig. 3. Using PSA, the expected time between accidents for the reactor fleet is once every 27. 8 years rather than once in 12,500 years, and the time between radioactive releases equals once in 111 years for the fleet 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, a NEA /OECD report [17] stated that Fig. 3 proves that the "predicted frequency for a large release of radioactivity from a severe nuclear power plant accident has been 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 global fleet reduction of severe accidents per year is only reduced by a factor of 3.55 = 1600 reactors / 450 reactors. The NEA statement confused probabilities to yield a misrepresentative and misleading statement. NEA analyzed calculations using an average probability rather than a cumulative probability, which yielded an error due to a fundamental misrepresentation of the data.

To be clear, the data from this figure proves that a severe accident in the world-wide reactor fleet is expected once in every 27.8 years – not once in every 12,500 years. To greatly understate the problem, interpretations are sometimes confused with respect to this graphic depiction of reactor accidents. Note that fleet frequencies for accidents around the globe are more applicable to an accident that may occur in any country with nuclear power operations, even though the PSA frequency for individual reactors is necessary for the safety analysis for each of those reactors. For this research the PSA fleet frequencies, or probabilities, are applicable. This conclusion is consistent with NUREG-2201 [18], which states that the CDF is approximately 0.005 for the U.S. reactor fleet (Fig. 3, US, PRA fleet CDF) with an uncertainty equal to an order of magnitude, and this NUREG also states that risk based information is not the sole basis for decisions. This recent work of the NRC moves toward a more appropriate representation of core damage risks. That is, some of the misrepresentations of WASH-1400 [22] are starting to be resolved.

Is This Error an Ethics Concern?

While this error certainly misrepresents the facts, one could argue that this error may be more of an oversight due to a lack of understanding, rather than a conscious effort to ethically mislead others. Even so, the intent of the OECD publication that presented this data was to promote nuclear energy, and in that spirit the data was not properly screened and understood. These latter actions cross the line into unethical behavior, and this discussion may be considered to be a thorny issue that may lead to significant debate – so be it, the discussion is important. In fact, this step into unethical behavior is one of the most important lessons to be learned by engineers about ethics.

An engineer needs to be on guard against a natural tendency to bias technical information to his own beliefs. For example, this author worked as a troubleshooter to solve complex fluid flow problems in piping systems for many years. In troubleshooting complex industrial problems, interviews with operators, engineers and managers are an essential tool that yields much information to solve problems. However, employees occasionally, without intent, filter information that they know to be true when they are interviewed. Basically, they leave out facts that do not agree with their conclusions of what they already think happened during a specific problem – the same can happen to one's own mind in an effort to achieve success.

Also, the pressures of cost and schedule are always an issue in research. Engineers want more money and time and managers want less in this perpetual divide between management and engineering.

As a specific example, this author[13] conducted a $1.5 million mixing research project at Savanah River Site to investigate the times required to mix nuclear waste in million gallon tanks for further processing. As the research budget increased, project management wanted research to be curtailed by demanding that this author provide conclusions and a signed report. This author did not believe that the data was sufficient to do so for this safety class research, and this author refused to write or sign a report, which elevated the issue to upper management. Anger and

[13] This example is one of several examples of management disagreements that risked career damage while employed at Savannah River Site. The details matter little to this paper, but difficult decisions were made to do what was believed to be right. These decisions often came with a cost, but in retrospect the cost has always been worth the conflict. Looking back on those conflicts is quite comfortable - integrity and honesty wear well over time. Early career decisions to go along with management, and ignore that gut feel that something was wrong, do not wear so well over time. For example, as a younger engineer during a 1989 Westinghouse, US Defense Department radar project, Management demanded that one of the review processes must be skipped during design to accelerate schedule. Compliance resulted in an error during later fabrication. Management then stated that they never made such a demand. Ethics was learned the hard way. Doing the next right thing is simpler, but not necessarily easier.

near-hatred ensued as the research report was blocked by this Principal Investigator, but management yielded to continue research funding. New information was found in the additional research that was essential to mixing success in the nuclear waste processing plant. The anger washed away as everyone took credit for doing a good job. This research was a great success, and all of the disagreeing parties were listed as coauthors to an ASME Magazine article [9]. In fact, the 5 author limit for the Magazine was waived by ASME on this author's request so that all 10 parties could be credited with this success, even though the success hinged on the initial refusal to sign an inadequate report.

There were three lessons learned from this project. First of all, two or three years are required before people forget the arguments and remember the success. Secondly, success can be defined as the situation when everyone who works on a project believes that they were the sole reason for the project success, and the fact is that they are all correct. And third, if the author had been wrong his career would have been severely damaged.

Herein lies a critical problem with ethics, when should you risk your job to do the right thing? The answer is all the time, but families need support, and the potential loss of employment is a factor that colors one's thoughts, since acting ethically may have less impact if your debts are paid. Sometimes jobs are lost even when ethics are practiced, and sometimes because ethical actions are practiced. Ethics is a matter of personal choice and responsibility, and the ethical choice is not always made in industry for reasons of cost, schedule, pressure by management and coworkers, pride, personal bias, and politics of course. When opinions differ, ethics serve as a resolution to conflict[14].

As a matter of fact, a job was quit at SRS due to such a conflict, and that action permitted the time needed to perform this research. In a letter to a Senior Vice President of SRS, the following statements were made.

"**THE REST OF THE STORY**, January 14, 2017

The main reason that I left SRS was a management demand to perform work that I believed to be substandard, and incompetent in my opinion, at a time when the … facility was in a state of Deliberate Operations. I had a terrific career at SRS, but it ended with some conflict. Overall, SRS was a great place to work, and consequently I struggled at whether or not I should write this letter at all. In fact, a year has passed since I retired, and my life is quite extraordinary. Even so, clarifying the reason for my abrupt retirement seems reasonable.

The issues at hand were schedule versus quality. Recurrent issues in some projects, engineers sometimes expect more technical investigation than management is willing to invest in. The balance between these two requirements is important to the success of any engineering project, and engineers and management work to solve this problem to obtain a cost effective solution that provides a technically competent outcome. In most cases, effective compromises are reached, but on occasion compromise is not reached. That is, engineering and management do not reach the same conclusion about what needs to be done. In my career at SRS, I have had several such disagreements ... I was pressured by management to perform work that I believed to be incompetent, and although I initially conformed to this request I finally decided to perform competent work in defiance of management demands… on a normally scheduled day off. My final calculations were used to provide recommendations to … Operations management ... On my own time, I published my new findings …"

MELTDOWN AND EXPLOSION PREDICTIONS

With a new understanding of existing fleet safety in hand, future fleet safety can be considered. Specifically, the next reactor meltdown and the next nuclear power plant explosion can be predicted. In the nuclear industry, there have been more than 20 criticality accidents, and there have been numerous meltdown accidents in commercial reactors, research reactors, and submarine reactors. This research is focused on nuclear power plant reactor accidents, and those accidents are listed in Table 1. In-service data from multiple countries represents power plant explosions and meltdowns due to the melting of single fuel rods, partial cores, or complete cores[15].

Accident frequencies are assumed to be random events throughout the fleet, regardless of design. The primary thread that connects these accidents is that loss of coolant results in all accidents, even though the random initiating cause of each accident may drastically vary as detailed in other publications associated with this research (Leishear [3 - 7]. A second thread that connects these accidents is the fact that explosions occur in every accident. The explosions may not cause damage as in the case of a partially melted fuel rod, or explosions can be large like the reactor breaches at Fukushima or Chernobyl.

[14] There is also a possibility that you are wrong and that your arguments only serve to alienate others, which can also happen when you are right. There is great sentiment throughout industry that one needs to go along to get along. Alternatively, you cannot argue with someone who does not care.

[15] Small piping explosions in nuclear plants are not included in this table.

Another common thread to every nuclear accident is the common belief that the design has been so well executed that an accident cannot occur. This belief occurs again and again, and is the most flagrant violation of ethics in the nuclear industry, since nuclear accidents continue their explosions into our world - again and again – as reactor safety is iteratively improved due to Lessons Learned from each accident. Overcoming this ethical dilemma is the purpose of this research to stop explosions, and the purpose of the following calculations is to predict the next meltdown and to predict the next preventable explosion so that action to stop explosions is taken.

A Previous Accident Prediction

A recent publication stated that the next nuclear accident is expected in approximately 10 to 20 years (Max Planck Institute [19]). The calculations were quite simple. The assumptions were that there have been 4 reactor meltdowns, which included 1 at Chernobyl and 3 at Fukushima. For the worldwide, civilian reactor fleet, the number of reactor years was divided by 4 to determine the number of hours to the next meltdown. Using reactor hours at the time of the 2011 Fukushima accident (14,500 reactor years of operation), and then and dividing by 4, a prediction is graphed in Fig. 4, such that

Accident prediction considering 4 accidents = 2019 to 2031 6

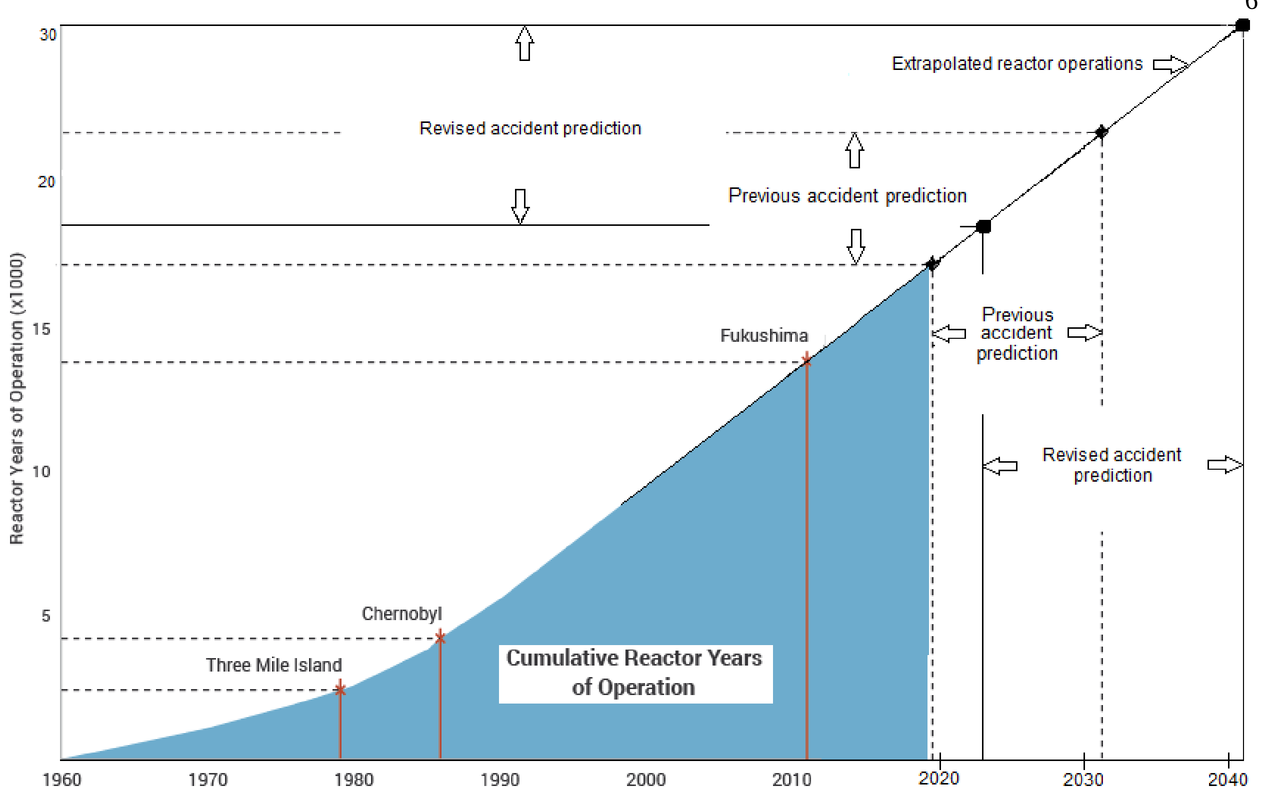

Figure 4: An Accident Prediction Based on Reactor Hours of Operation (Predictions from the Max Planck Institute [19] and Leishear [Eq. 8]. This figure was adapted from the World Nuclear Association [20])

Based on this number, those authors estimated that the next accident will occur 10 to 20 years after Fukushima. Note that the 8 year minimum prediction (2019) provided in Eq. 6 is slightly less than their 10 year minimum prediction for an accident, and this 8 year prediction is the sole calculation provided by the Max Planck Institute research to conclude that there will be 10 to 20 years between accidents. To augment their solution, a prediction of the maximum time between accidents is determined here by comparing the areas under the Fig. 4 curve before and after the Chernobyl accident. Considering the nonlinear nature of reactor operating hours, this comparison of areas yields a relationship to yield a 20 year maximum prediction between accidents. Accordingly a model for the next accident is actually 8 to 20 years between accidents, i.e., an accident is predicted between 2019 and 2031.

Although not considered in their paper, the results are different if three accidents are considered, i.e., TMI-2 is neglected, Saint-Laurent is one accident, Chernobyl is one accident, and Fukushima is one accident. Then the accident predication is 16 to 40 years between accidents. The revised method yields

Meltdown prediction considering 3 accidents = 2027 to 2051 7

Note that this prediction will increase - more than double - if the areas under the Fig. 4 curve are considered before and after Saint-Laurent, rather than before and after Chernobyl.

If TMI-2 and Saint-Laurent are neglected[16], and assuming that Chernobyl is one accident, Fukushima is one accident, then the accident prediction for therevised method yields 12 to 30 years between accidents, such that

Meltdown prediction considering 2 accidents = 2023 to 2041 8

Note that these equations assume that the hours of nuclear reactor operations will remain constant in future years, that uncertainties (*U*) cannot be determined for these go – no go predictions, and that all of the reactor accidents before TMI-2 are negligible contributors to future accident predictions, which is a reasonable assumption due to the major fleet improvements after TMI-2.

Figure 4 shows this accident prediction in addition to the original accident prediction by the Max Planck Institute. That is, predictions are shown on this figure for the cases where the Fukushima explosions are considered as either one accident or three accidents. Consistent with analysis below, this author endorses the prediction that considers Fukushima to act as a single accident, although there were multiple meltdowns and explosions.

Also note that the Max Planck Institute researchers did not consider the frequency of nuclear power plant explosions, which is the focus of this research. This research can ensure that explosions and large radioactive releases cannot occur even if there is a meltdown.

Predictions of the Next Accident Using Statistics

Statistics are needed to evaluate reactor safety with respect to past and future accidents, where the use of statistics is defined by the Oxford dictionary as “the practice or science of collecting and analyzing numerical data in large quantities, especially for the purpose of inferring proportions in a whole from those in a representative sample.” As such, statistics represents a mathematical description of facts to describe a random sequence of events (Coleman [21]. Simply stated, statistics is accepted in all scientific fields of study to explain physical processes to provide reasonable predictions.

Even so, inferred statistics are presented here, where future predictions are made, based on previous explosions. The methods presented are consistent with mathematical statistics as used with small sets of data. 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, where probability theory is integral to nuclear industry safety.

There are many statistical methods that provide different information. Multiple methods sometimes provide different answers to the same problem. Some of these methods follow and will be assessed for applicability to explosion predictions.

An Accident Prediction Using a Hypergeometric Distribution

A continuous statistical distribution can be used to predict whether or not a nuclear accident will occur, where the Hypergeometric model is such a distribution that is applicable to power plant explosions. This model is one of few models that account for a finite population without replacement, which assumes that damaged reactors are permanently removed from service (Modarres, et al [16]). Replacement of a reactor back into service may be permitted for small damages to fuel rods but not permitted for large damages such as those at Fukushima and TMI-2. The assumption of no replacement is an approximation.

Assuming that the population equals 450 reactors from Fig. 2 (the number of in-service reactors varies due to new construction and decommissioning), and assuming that the number of previous accidents equals 11, the number of damaged reactors after the next accident equals 12, and the number of undamaged reactors that are potentially included in the next predicted accident equals 439, the hypergeometric probability is found to be 26% using Excel®.

Hypergeometric accident prediction = 0.26 = 26%

[16] Note that significantly different accident predictions are easily obtained, using Eqs. 6 through 8. There is no ethical concern with respect to the Institute research, but a difference in engineering judgement affected the selection of accident predictions presented here. Note that these calculations (Eq. 6) predicted that an accident should have already occurred in 2019, and an associated, unsupported estimate predicted that an accident will occur in the next 10 to 20 years, i.e., 2021 to 2031 (Max Planck Institute [20]).

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Note that this value is an order of magnitude higher than the PSA fleet frequency shown in Fig. 3, which predicts the twelfth nuclear power plant accident.

Also note that there is a one in four chance that a reactor meltdown will occur. That is, a meltdown is expected in the existing reactor fleet, even though the probability of not having an accident is greater than the probability of an accident. Additionally, the accident probability of a meltdown at any specific reactor is one in 1733, given that 11 meltdowns have already occurred. This probability ($5.77 \cdot 10^{-4}$ accidents per year = hypergeometric frequency prediction) is more than an order of magnitude higher than the average fleet CDF shown in Fig. 3. This conclusion is reasonable given that this CDF prediction considers the fact that there have been 11 earlier core damage accidents, while other predictions in Fig. 3 do not account for earlier accidents by predicting the first accident occurrence.

While the probability of whether or not an accidental meltdown will occur is certainly of interest to this research, a prediction of when that accident will occur is far more important, and linear regression analysis is recommended and discussed as follows.

Accident Predictions Using Linear Regression Analysis

Linear regression analysis is a well-known statistical model (Coleman and Steele [21]), and that technique is used here to provide various predictions of the times to the next meltdown, the next explosion, and the next criticality. Both CDFs and LRFs are determined here, and calculation results are presented in Tables 1 and 2 and plotted in Figs. 5 and 6, where these results are new to the literature. Figure 5 shows greater technical detail to support discussions, and Fig. 6 provides the results in an easier to read format with different supporting notations.

These bar graphs are set up so that the slope of any line equals the

$$(\textit{Time between accidents, Years}) / (\textit{Accident}) = \textit{Years / Accident}$$

10

Equations are determined from the bar graphs (Figs. 5 and 6), which extrapolate the twelfth meltdown accident from the earlier meltdown accidents. This extrapolation is similar to having stacks of quarters that are earned on 11 successive days. Rather than find an average to be expected on the twelfth day, the heights of the coin stacks are used to predict how much will be earned on the twelfth day. Plotted to the left hand side of the figures, bars are added indicate the next large radioactive release and the next Chernobyl type criticality that may have a large radioactive release associated with that criticality, where probability calculations are used to predict these values.

To perform these calculations, linear regression is implicit in Excel® models for graphing straight lines or parabolas, where regression equations are the mathematical basis for plotted displays. Excel® also has the ability to force curves to plot through zero, and this feature should not be used when considering statistical data. As noted by Coleman and Steele [21] and other authors, this practice skews the data through a theoretical point that was not experimentally validated. However, if there is a known point in a data set that equals zero, zero can be included as one of the plotted points to form a curve. For example, if a straight line or parabola is plotted for accidents after TMI-2, a zero value marks the time that TMI-2 occurred, and this zero value can be used to provide an additional data point to be included in the data set that forms the straight line or parabola. An additional data point is important to minimize uncertainties that are calculated using student-T values.

Since scant data is available due to few explosions and meltdowns, student-T values (Coleman and Steels [21]) are used to determine the uncertainties of the linear regression results for rare and infrequent events. Basically, linear regression is used to provide a representation of reactor accidents with respect to time, and student-T values account for the limited data. This data can be represented as a straight line or any other continuous curve. For this work, explosions and meltdowns are coincident lines, noting that explosions can be small or large. Uncertainties for data points on these lines equal the standard deviation times the student-T, such that

$$U = \sigma \cdot (student - T)$$

11

Appropriate linear regression equations from the literature are used to determine uncertainties as required.

Excel® has the added benefit of providing R-squared values (R^2) for each curve that is calculated. The R^2 values vary between 0 and 1 and provide a numerical description of how well a straight line or curve fits the data[17]. If R^2 equals zero, there is no correlation between a line and the data points. A zero R^2 value is the case for a single point,

[17] As defined in Excel®, R equals the Pearson function and reflects the extent of a linear relationship between two data sets, and R^2 describes the proportion of the variance in y attributable to the variance in x, i.e., the correlation between two data sets – in this case the correlation between a set of discrete data points and a curve or line.

where the uncertainty is undefined. If R^2 equals one, there is complete correlation between a line and the data points, and the uncertainty is zero. This is the case when two points are theoretically exact and plotted with a straight line between them. However, an uncertainty can be calculated for two points and a line with known errors. The qualitative R^2 numerical values provide no numerical information at all about uncertainties for plotted data in between the R^2 limits of 0 and 1. Even so, the lower the R^2 value, the greater the uncertainty. The following linear regression models are presented in terms of U and R^2 as required.

A Fleet Accident Prediction, A Straight-Line, First Order Model

A straight-line model is used to predict fleet accidents, which is based on the accident data for all 11 meltdowns. Excel® plotted the line shown in Figs. 5 and 6, and Excel® yielded the prediction of a meltdown in 2022, such that

$$Curve\ A\ \rightarrow y = 1.0029 \cdot x - 0.8632,\ R^2 = 0.2805 \text{ (Figs. 5 and 6)} \tag{12}$$

By substituting the number 12 (the twelfth accident / predicted accident) into this equation and adding the result to 2011.25 (The Fukushima accident date was March 2011) the meltdown prediction can be found for any equation that represents a meltdown prediction. For this example,

$$y = 1.0029 \cdot 12 - 0.8632 = 11.17 \tag{13}$$

$$\textit{Meltdown prediction} = 2011.25 + 11.17 \approx 2022 \tag{14}$$

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

This equation is dismissed as being non-representative of accident predictions for the present reactor fleet since the R^2 value is so low. The errors in this equation are primarily due to the marked increase in the mean time between accidents that followed TMI-2 induced fleet improvements. Even so, this model proves that the TMI-2 actions remarkably improved accident prevention, and proves that far more frequent accidents would be expected in the absence of those actions. In fact, an accident would be due right now in the absence of earlier fleet improvements. This conclusion can also be readily reached by observing the 11 accidents that are shown in the figure. Prior to TMI-2 the longest time between meltdowns was 6 years since nuclear power plants started operations.

Higher order parabolic models were also considered for the fleet, but these models did not provide additional insight into the nuclear fleet's accident performance. For example,

$$Curve\ B\ \rightarrow y = 0.3039 \cdot x^2 - 2.34 \cdot x + 4.7083,\ R^2 = 0.5209 \tag{15}$$

$$\textit{Meltdown prediction} = 2031 \tag{16}$$

A Post-TMI-2 Accident Prediction, A Simplified Model

The simplest model that can be obtained on Fig. 5 neglects uncertainties and simply plots a straight line from the point at which the TMI-2 accident occurred at time = 0 to the point at which the Fukushima accident occurred 32 years later. This prediction yields

$$Curve\ D\ \rightarrow y = 8.305 \cdot x,\ R^2 = 1 \tag{17}$$

$$\textit{Meltdown prediction} = 2045 \tag{18}$$

A Post-TMI-2 Accident Prediction, A Straight-Line Model

The striking change in accident frequencies after TMI-2 requires that any modeling of future accidents cannot depend on the previous accident history of other reactors prior to TMI-2 even though that history proves that there were long term safety problems in the nuclear industry prior to TMI-2. Straight-line accident models using linear regression are legitimate and readily provide standard deviations (σ), which can then be multiplied by student-T factors to determine the uncertainties of meltdown and explosion predictions.

A straight-line model for post-TMI-2 accidents is shown in Figs. 5 and 6, and supporting data is provided in Tables 1 and 2. Uncertainties were calculated according to (Coleman and Steele [21]) for the Standard Error of Regression (S_y), which is the uncertainty of a straight line in the *y* direction in Fig. 5. Then,

$$S_y = \left(\frac{\sum_{i=1}^{n} (y_i - m \cdot x_i - c)^2}{n-2} \right)^{1/2} \quad 19$$

Calculation results

1. The straight-line model for the Post-TMI-2 meltdowns is extrapolated to the next future meltdown date, and this model is reasonable based on the data, such that

$$Curve\ C \rightarrow y = 7.9831x - 67.84,\ R^2 = 0.791 \text{ (Table 2, Figs. 5 and 6)} \quad 20$$

The fact that $R^2 = 0.79$ indicates that the uncertainties are rather high, which is true. Even so, these equations and applicable uncertainties are valid. The time to the next power plant meltdown after Fukushima is determined from

Mean time to the next accident = 27.96 years - 15.27 years with 95% confidence, single tail probability 21

The uncertainty is determined by using σ = 6.49 years and a student-T = 2.3534 for the four sample data set of TMI-2, Saint-Laurent, Chernobyl, and Fukushima. A normal, Gaussian distribution and a single tailed probability is assumed for this calculation (Fig. 7). This data set is pertinent and includes the TMI-2 reactor improvement effects on meltdown probabilities, and the effects of additional reactor safety improvements following Fukushima are approximated to be proportional to TMI improvement effects. In short, there is a 1 in 40 probability of a meltdown in 2024, and there is a 50% probability that a meltdown will occur before 2039, since the

Meltdown prediction = 2039 - 15 years with 95% confidence, single tail probability 22

2. The mean time to the next large release is predicted in 2067, with a 1 in 40 probability of a large release in 2054. 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". For the four reactor set/group under consideration, one of two explosions and one of two large releases are caused by fluid transients. 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. 3) 23

Meltdown prediction = 2067 - 30 years with 95% confidence 24

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", since the only potential release will be caused a Chernobyl type accident. By implementing corrective actions to stop fluid transient induced explosions, the mean time to the next large release is predicted in 2090, with a 1 in 40 probability of a large release in 2025, 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. 3 and 8) 25

Large release prediction = 2090 ± 64 years with 95% confidence 26

4. A lack of regulatory control, safety culture, and developing technology have been used to differentiate between accidents in OECD and non-OECD countries (NEA [17]), and these issues have been used to discount Chernobyl effects on accident evaluations. Chernobyl is important to the limited data set under consideration, but predictions due to significant effects from Chernobyl data are primarily limited to the prediction of the next criticality accident. The prediction for the next nuclear power plant criticality is predicted as

$$\textit{Meltdown prediction} = 2090 \pm 64 \text{ years with 95\% confidence} \quad (27)$$

The significant uncertainty is due to the fact that there is only one data point (Chernobyl) in the accident data set that is used for these calculations.

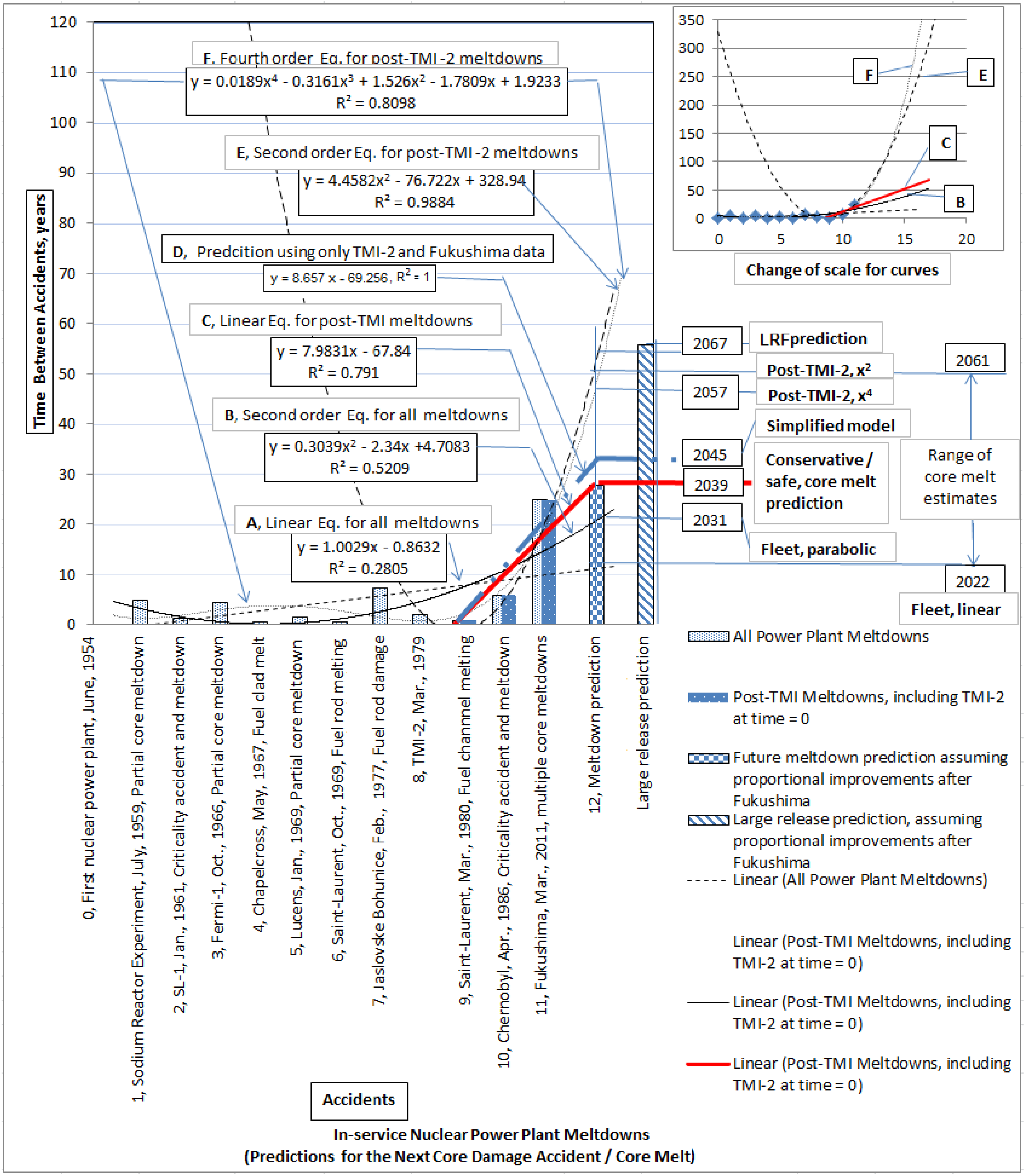

Figure 5: Nuclear Power Plant Accident Predictions[18]

[18] This graph is new to the literature.

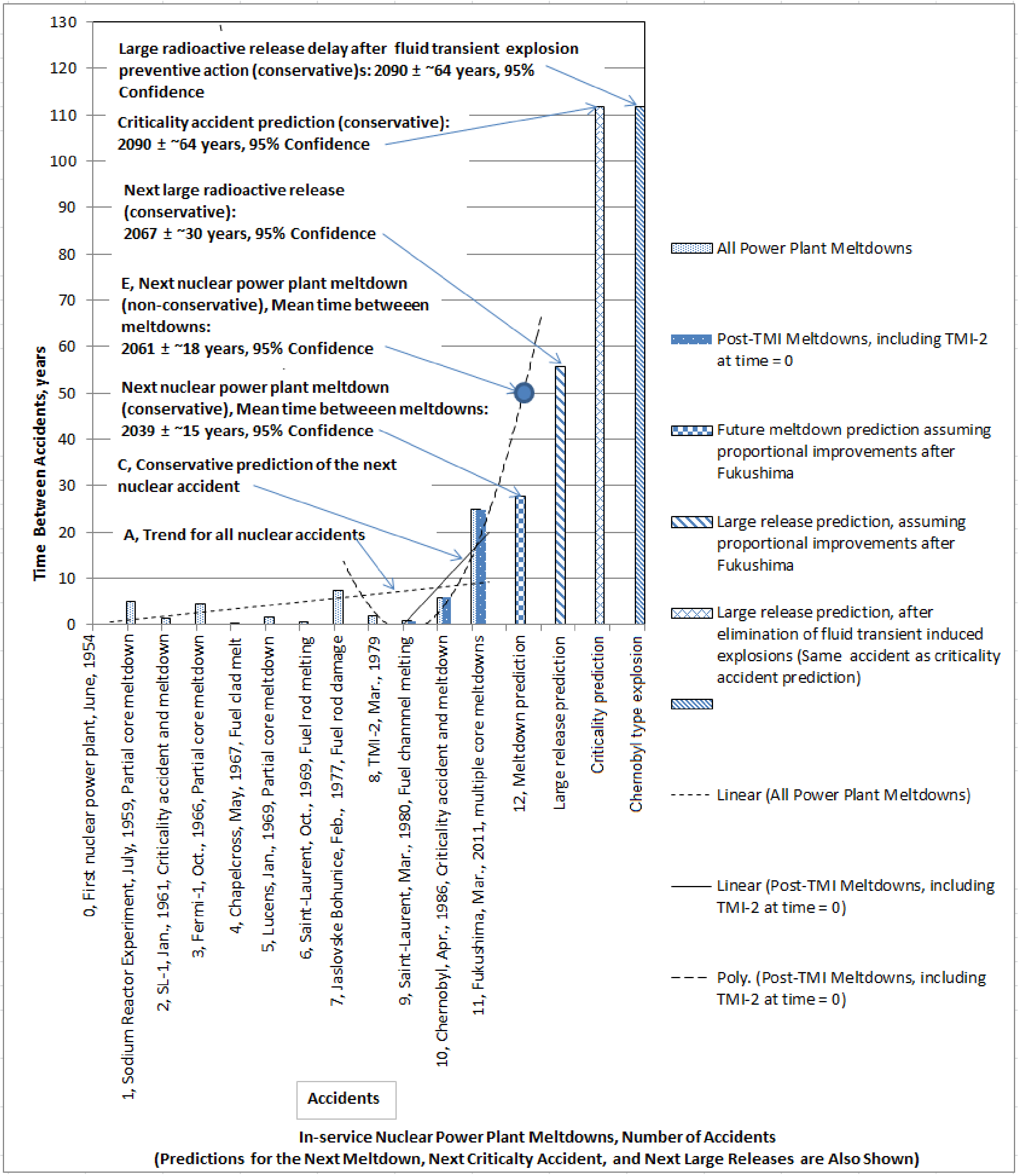

Figure 6: Nuclear Power Plant Accidents, Prediction Results[19]

[19] This graph is new to the literature.

A Post-TMI-2 Accident Prediction, Parabolic Models

Two parabolic models were evaluated for meltdown predictions, i.e., a second order model and a fourth order model, where

$$Curve\ F \rightarrow y = 0.0189 \cdot x^4 - 0.3161 \cdot x^3 + 1.526 \cdot x^2 - 1.7809 \cdot x + 1.9233,\ R^2 = 0.8098$$ 28

Meltdown prediction = 2057 29

$$Curve\ E \rightarrow y = 4.4582 \cdot x^2 - 76.722 \cdot x + 328.94,\ R^2 = 0.9884$$ 30

Meltdown prediction = 2061 31

Considering the R^2 values, the second order model provides a better curve fit. In fact, this curve fit is the best fit for any of the models considered in this work.

The Standard Error of Regression, which is the uncertainty of the parabolic curve in the *y* direction in Fig. 5 equals

$$S_y = \left(\frac{\sum_{i=1}^{n} (y_i - 4.4582 \cdot x_i^2 + 76.722 \cdot x_i - 328.94)^2}{n-2} \right)^{1/2} = 7.554\ years$$ 32

$$U = 7.554\ years \cdot 2.3534 = 17.78\ years$$ 33

Meltdown prediction, Single tail probability (student-T = 2.3534) = 2061 - 18 years with 95% confidence 34

Meltdown prediction, Two tail probability (student-T = 3.182, σ = 7.554) = 2061 ± 24 years with 95% confidence 35

Note that Eq. 34 predicts when the next meltdown will occur using a second order parabolic model, such that there is a 5% probability of a meltdown before 2043 and a 50% probability of a meltdown before 2061. Also, Eq. 35 predicts that there is a 95% probability of a meltdown before 2085, i.e., there is not only an unsafe situation due to an expectation of a meltdown before 2061, but the math proves that a meltdown in the worldwide fleet is nearly certain before 2085, and this parabolic model also exceeds the 95% predictions of the straight-line model (Fig. 7). In other words, there is a at least a 95% probability for a meltdown before 2085 for the models considered here.

Modeling Summary

To compare the models, pertinent equation results are rewritten.

Meltdown prediction by others considering 2 accidents = **2019 (**predicted accident by others) to 2031 (Eq. 6) 36

Modified meltdown prediction considering 3 accidents = 2027 to 2051 (Eq. 7) → $\mathbf{2039_{average}}$ 37

Note that Eq. 37 is endorsed rather than Eq. 36 for consistent comparative results, i.e., data from Fukushima, Chernobyl, and Saint-Laurent are evaluated for Eqs. 37, 39, and 40, and the TMI-2 accident represents time = 0 for calcualtions.

Simplified meltdown prediction = **2045** (Eq. 18) 38

Straight-line, First order, meltdown prediction = 2039 - 15 years with 95% confidence (Eq. 22) → $\mathbf{2039_{average}}$ 39

Parabolic, Second order, meltdown prediction = 2061 - 18 years with 95% confidence (Eq. 34) → $\mathbf{2061_{average}}$ 40

Several meltdown predictions provide nearly the same information. Specifically, the straight-line average value specified by Eq. 39 ($\mathbf{2039_{average}}$) equals the average prediction of Eq. 37 ($\mathbf{2039_{average}}$) that was modified from the work of earlier researchers (Eq. 7), and the Eq. 37 straight-line prediction also encompasses the simplified prediction of Eq. 38 (**2045**). The only prediction that stands out is the parabolic prediction ($\mathbf{2061_{average}}$), where the mean time to a meltdown is predicted to be 22 years more than the straight-line prediction. In other words, one set of calculations predicts a meltdown in about 20 years, and another calculation predicts about 40 years to the next meltdown. Either way, a meltdown is expected in the near future.

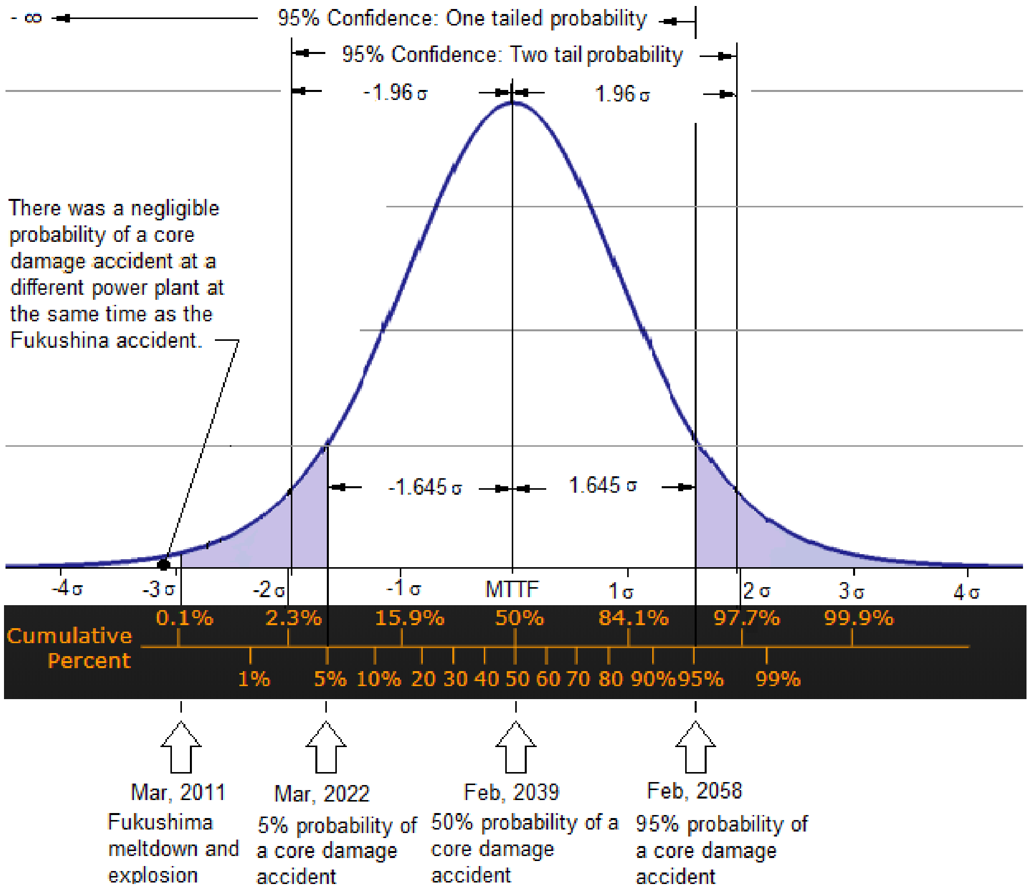

Figure 7: Probability of the Next Core Damage Accident With 95% Confidence With Respect to the Mean Time to Failure for an Accident Using a Normal Distribution and a Two Tailed Probability or One Tail Probability

A problem of ethics vs. engineering judgement arises. Engineering judgement provides predictions based on an engineer's experience, skill, and education, i.e., an engineering technical opinion[20]. On the one hand, the parabolic model is a mathematically more precise curve fit, and this second order model may actually reflect the effects of post-TMI-2 fleet improvements more accurately. On the other hand, the linear model could better suit a perception of the author's interest to magnify the importance of this research. The sooner that an accident is expected, the sooner that research needs to be completed and implemented. However, both methods are statistically correct when uncertainties are included in the calculations (Fig. 8). The straight-line prediction is statistically more accurate (slightly), or correct, with respect to uncertainties, even though the parabolic model fits the data points better than the straight-line model. Additionally, a meltdown is predicted before 2085 with at least 95% confidence. These predictions present a wide range of approximations, and the question must be asked, is the data reasonable to be used for nuclear reactor safety? Since probability is an accepted method for safety analysis, the answer is yes. Which model approximation should be used? Since reactor safety is in question, engineering judgement and safety dictate that the more conservative model should be used, which is the straight-line model that predicts a 2039 meltdown date. For this reason, predictions for large radioactive releases and criticalities were only performed above for this model that predicted a meltdown in 2039 (Eq. 38, Table 2, and Fig. 6). Based on Fig. 8, a meltdown has at least a 50% probability between the 2039 prediction and the non-conservative 2061 prediction. However, the 50% probability of a conservative 2039 prediction is endorsed here to ensure protection of people, property, and the

[20] Engineering judgement is essential in design and operations when partial information is unknown, indeterminate, or irretrievable.

environment, and that prediction is coupled with a prediction that there is a 5% probability of a meltdown before 2024. That is, an accident is imminent, i.e., there is a 1 in 20 probability of a meltdown by 014 and less than a 1 in 1000 probability of a meltdown in 2020.

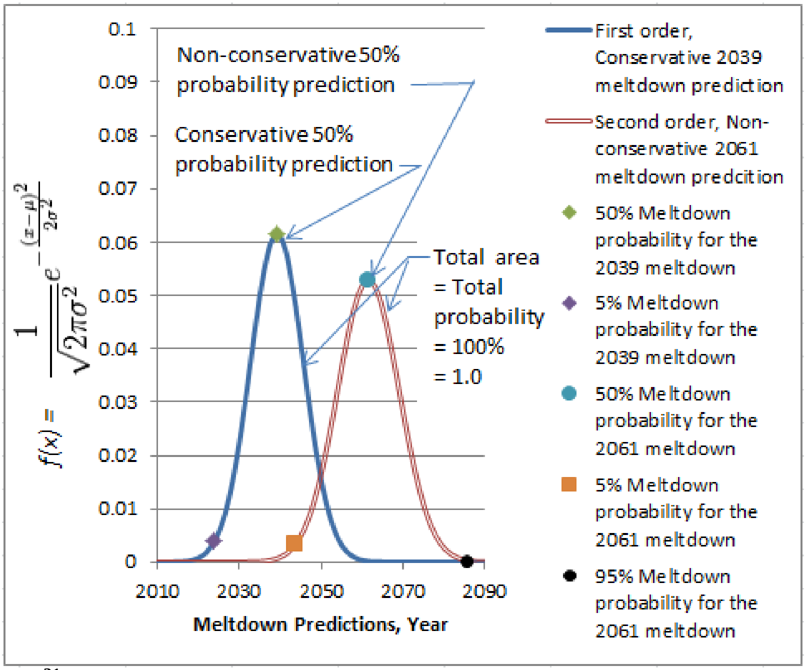

Figure 8[21]: Comparison of First Order and Second Order Meltdown Predictions

Summary of In-Service Fleet Accidents[22]

To introduce accident models, graphic displays of severe accident predictions are provided to present the new findings in this discussion (Figs. 3 and 9), where technical proof is essential to background these significant discoveries. As shown in Fig. 3, mathematical PSA values are called into question since in-service, or actual, fleet frequencies (Eq. 2 and 3) are higher than the PSA values (Eqs. 4 and 5). In short, the in-service, fleet frequencies are based on experimental fact, i.e., 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 fleet model results showed that the next major nuclear accident is anticipated in 2127 (Eq. 4), but this work predicts an in-service fleet accident in 2039.

However, this study of in-service nuclear 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 at any time with a small probability, and a meltdown is predicted before 2039 with a 50% probability. Similarly, the next major radioactive release like Fukushima or Chernobyl is expected to occur before 2067 with a 50% probability. 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 2090 with a 50% probability.

[21] This graph is new to the literature.

[22] Accident predictions are presented for the worldwide reactor fleet, and US predictions will of course be affected by the fact that US reactors comprise approximately 21% of operating reactors, since there are presently 96 operating reactors in the US and 449 operating reactors around the world. That is, the probability equals $0.21 \cdot 0.5 =$ 11% for an explosion to occur in the existing U.S. fleet before 2039.

Table 1: Power Plant Meltdown History, Years Between Accidents

All power plant meltdown accidents. The magnitude of the meltdowns are not distinguished for these accidents, i.e., core damage = meltdown for this table.	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, conservative	12	---	---	27.96
Meltdown prediction, non-conservative				50.26
Large release prediction, conservative	---	---	---	55.91
Criticality accident prediction, conservative	---	---	---	79.33
Large release prediction with corrective actions, conservative (Same prediction value as the criticality accident prediction)	---	---	---	79.33

Table 2: In-service, Fleet Accident 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	27.96	TMI, etc., y = 7.9831x – 67.84	55.91	TMI, etc., y = 2·(7.9831x – 67.84), years	79.33
σ, years	6.49	σ, years	12.98	σ, years	25.95
95% Confidence, years	15.27	95% Confidence, years	30.53	95% Confidence, years	64.85
Student-T	2.3534	Student-T, Single tail	2.3534	Student-T, Single tail	2.3534
Next meltdown prediction, year	2039.2	Next release prediction, year	2067.2	Next release prediction, year	2090.6
Near term meltdown prediction, year	2023.94	Near term release prediction	2036.6	Near term release prediction, year	2025.7
Long term meltdown prediction, year	2054.47	Long term release prediction	2097.7	Long term release prediction, year	2155.4
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

To better understand these predictions, the applied 95% confidence level represents a one in twenty chance of an event occurring. This confidence level is commonly used throughout many industries including nuclear facility instrumentation, where this 95% confidence level was assumed here for calculations, even though a case can be made to use a 99% confidence due to the importance of the results. A 99% confidence level shows that an accident and large radioactive release is more likely to happen at any time, but the mean time to the next power plant meltdown or radioactive release remains the same. For 99% confidence calculations a student-T value = 1.838 would be used instead of the 2.3534 student-T value that is used in uncertainty calculations for this work. This different student-T value would then be substituted into all single-tail probability calculations above. A single-tail probability was selected since the interest is in near-term explosions, and the two-tail probability would describe both near-term core damage predictions and far-term predictions that would occur long after the mean time to a core damage accident and explosion. Also, the effects of Lessons Learned from Fukushima may affect this meltdown prediction, but cannot be concisely quantified. An implicit assumption is that the ongoing Fukushima Lessons Learned are as effective for future nuclear plant operations as the earlier TMI-2 Lessons Learned with respect to reactor safety improvements.

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 ~28 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.

Of particular interest to fleet accidents, the Chernobyl accident was dismissed as being applicable to meltdowns in other countries. Since the Chernobyl design was of Russian origin, the opinion was that the design was not as safe as other reactor designs, and that the Chernobyl accident was inapplicable to other safety analyses. In fact, Japanese reactor workers were taught that a reactor accident was impossible prior to Fukushima. As a result of this incompetent direction to workers, the National Industrial Safety Administration was shut down in Japan and a new organization – with greater credibility – was replaced by a new Nuclear Regulation Authority in Japan. The OECD and the U.S. NRC also promoted the opinion that any, and all nuclear accidents could not happen, which was, of course, also proven incorrect by the Fukushima explosions. In other words, Probabilistic Safety Analysis had incorrectly proven that reactor accidents were beyond extremely unlikely, but reactor explosions occurred regardless of theory. Predictions based on what was known at that time were proven to be incorrect. We do not know what we do not know.

Two facts are certain from this research. The fluid transient cause of nuclear power plant explosions has not been considered by any government regulator or plant operator in any country that operates nuclear power plants, and the omission of facts in government reports during previous investigations has delayed this finding for decades.

PSA ACCIDENTAL DEATH FREQUENCIES VERSUS RISKS FOR THE ENERGY INDUSTRY

Previous NRC accident data [22] incorrectly and unethically shows that nuclear plants are much safer than other energy industries. To do so, NRC accident frequency data rather than risk data was used to compare nuclear power plant accidental deaths to other industrial deaths, as shown in Fig. 9. Not only did this document misrepresent the facts, but this decision had a ripple effect throughout the nuclear industry, where NRC documents and other documents continue to use this reference. For example, a textbook currently used for teaching nuclear engineers (Knief [23]), presents Fig. 9 in the unedited format. Knief provided this information with integrity, but the NRC did not perform due diligence before publishing this misleading, and consequently unethical presentation of data. Knief's text followed the NRC path to claim that "the most likely core meltdown accident has modest consequences to the public", where consequences were not technically considered at all in the NRC report (NRC [22]). Consequently, nuclear engineers have believed this fallacy for years, which they were taught in universities. One may claim that the NRC did the best that they could, but the definition of risk has long been known, and for the NRC to ignore known technology to yield a favorable outcome is unethical.

An Ethics Problem with the Use of Frequency Data Instead of Risk Data

For example, by considering frequencies alone, Chernobyl deaths appear to have less significance than 5 deaths in the oil industry, and even the deaths of 31 workers subjected to high radiation exposures who died within three months (two died at the scene) of the Chernobyl accident have less significance than 5 deaths in the oil industry. Equating the Chernobyl accident to a pipeline accident using frequency is entirely unacceptable. The ethics issue arises due to the manipulation of data, since risk equals the accident frequency multiplied times the accident consequence. Using only the frequency half of the risk equation, Fig. 9 readily concludes that the nuclear industry is far safer than any other industry. However, considering consequences as half of the risk equation, conclusions markedly change. Risk assessment is a well-known method to compare the importance of accidents, and the risk equation is the baseline for all risk assessments. Using only half of the risk equation to compare accidents is certainly unacceptable. In other words, the NRC not only falsified information about the TMI-2 explosion, but they falsified subsequent reports to make the reactor fleet appear to be safer than it is. These NRC actions are not only unethical, but these actions constitute malfeasance, especially when lives are at stake.

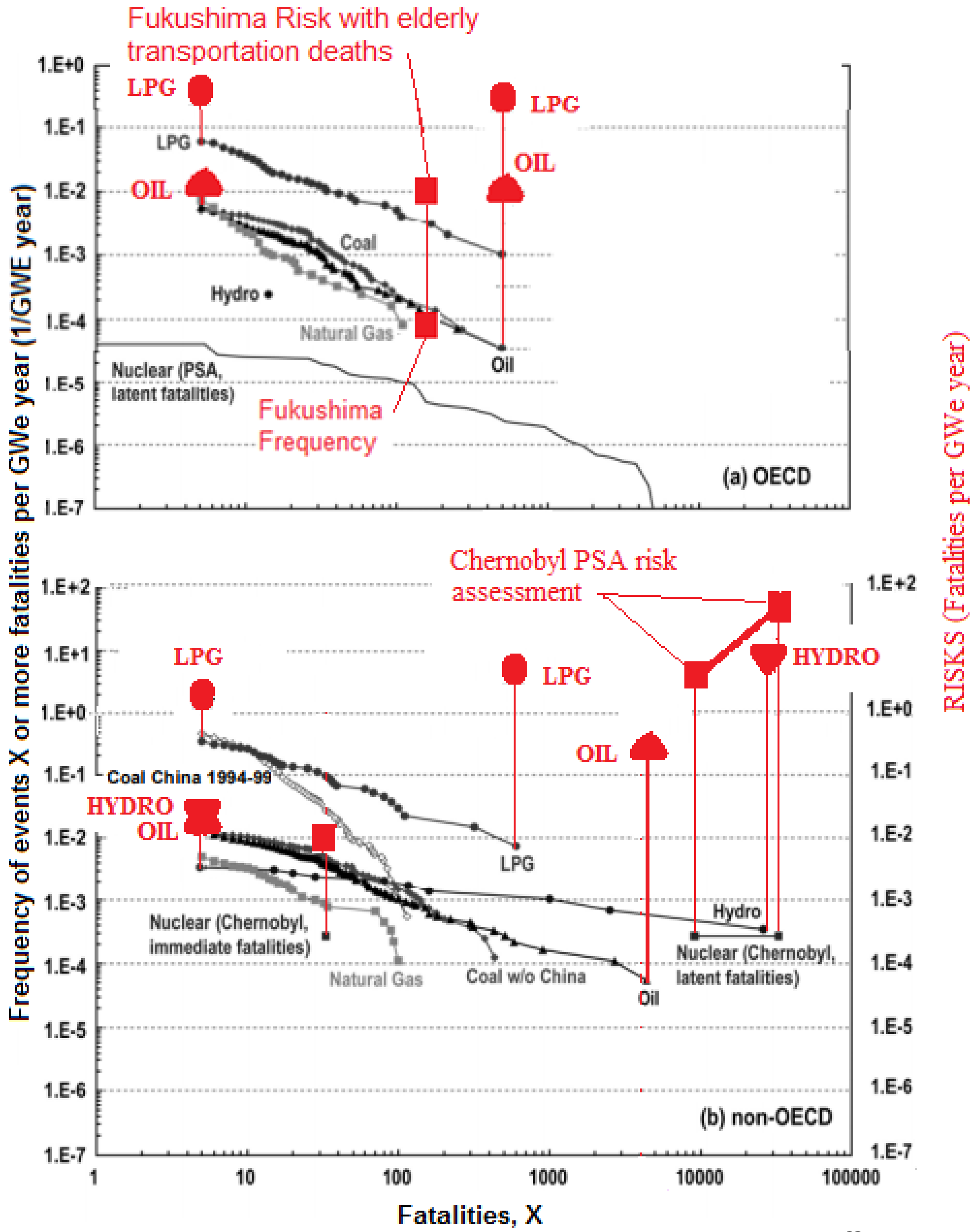

Figure 9: Frequency vs. Consequences and Risk vs. Consequences for Severe Accidents[23] (Deaths ≥ 5)[24] (Note: All data for 1969 – 2000, 31 years, except China coal, 1994-1999, and Fukushima, 1990- 2011, 31 years. Adapted from NRC, WASH-1400 [22]. TMI-2 is not shown since fatalities did not occur, and a zero risk is undefined on a log chart.)

[23] 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 [17]).

[24] Revisions to this figure are new to the literature, and were previously neglected.

Additionally, the use of PSA risk calculations, instead of frequency calculations, effectively weights the deaths caused by accidents in different industries, 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 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. 9 to compare nuclear energy accidental death risks to risks associated with other energy industries.

Cancer risks

Cancer risks may also be considered, since explosive, radioactive releases may cause thousands of cancer deaths. There were no deaths at the time of the TMI-2 accident, cancer risks from TMI-2 are generally considered to be negligible, and the resultant accidental death risk equals zero. Chernobyl cancer risk estimates are provided by NEA in the figure, but cancer risk estimates vary considerably as shown by the range of Chernobyl latent deaths in Fig. 9 (World Health Organization [24]). 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 [25]). Even though cancer risk data is plotted in Fig. 9, the use of risk data based on cancer estimates is questionable, since 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 with respect to cancer deaths.

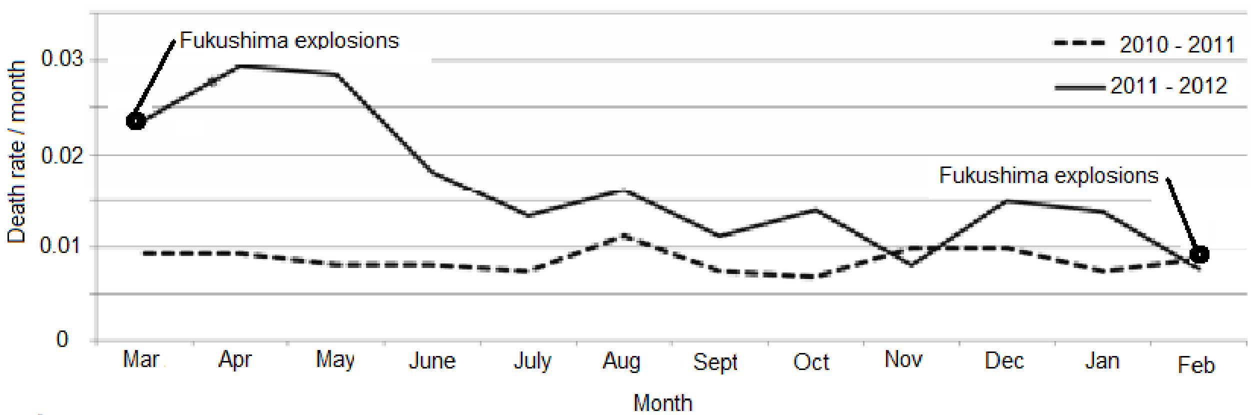

Figure 10: Mortality Rate Change for Institutionalized Elderly Due to Fukushima Explosions (Adapted from Yasumuru [26]).

Power plant accident risks and safety

However, these observations about cancer related data do not change the conclusion that risks are better suited to compare different types of accidents, and that risks due to immediate deaths for Fukushima and Chernobyl are comparable to death rates in other energy industries. For example, approximately 141 people died[25] due to the Fukushima 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 (Fig. 10). In other words, there is an accidental death risk for Fukushima due to evacuation related deaths, shown in Fig. 9, where calculations were performed by using Eq. 1 and Fig. 10 for a 31 year time span (similar to NEA data [17], Fig. 11), such that

$$Fukushima\ Accident\ Frequency/\ GWe \cdot year = 1/12405\ GWe \cdot year = 8.06 \cdot 10^{-5} \qquad 41$$

$$Fukushima\ Accident\ Risk, Fatalities/\ GWe \cdot year = 141/12405\ GWe \cdot year = 1.14 \cdot 10^{-2} \qquad 42$$

[25] Note that social and economic impacts caused by accidents are not included in Figs. 8 and. 11. Wheatley, et al [27] provide a discussion of costs due to nuclear accidents. These topics are outside the scope of the present work. A discussion of risks in different industries is also available from Romney and Duffey [28].

All in all, nuclear power plants are not significantly safer than other energy industries. PSA frequency presentations skewed available data to provide results favorable to the nuclear industry, where appropriate in-service fleet risks provided less favorable results than fleet frequencies. Accidental nuclear power plant deaths are comparable to the risks of other fuel industries, which is contrary to earlier nuclear industry reports.

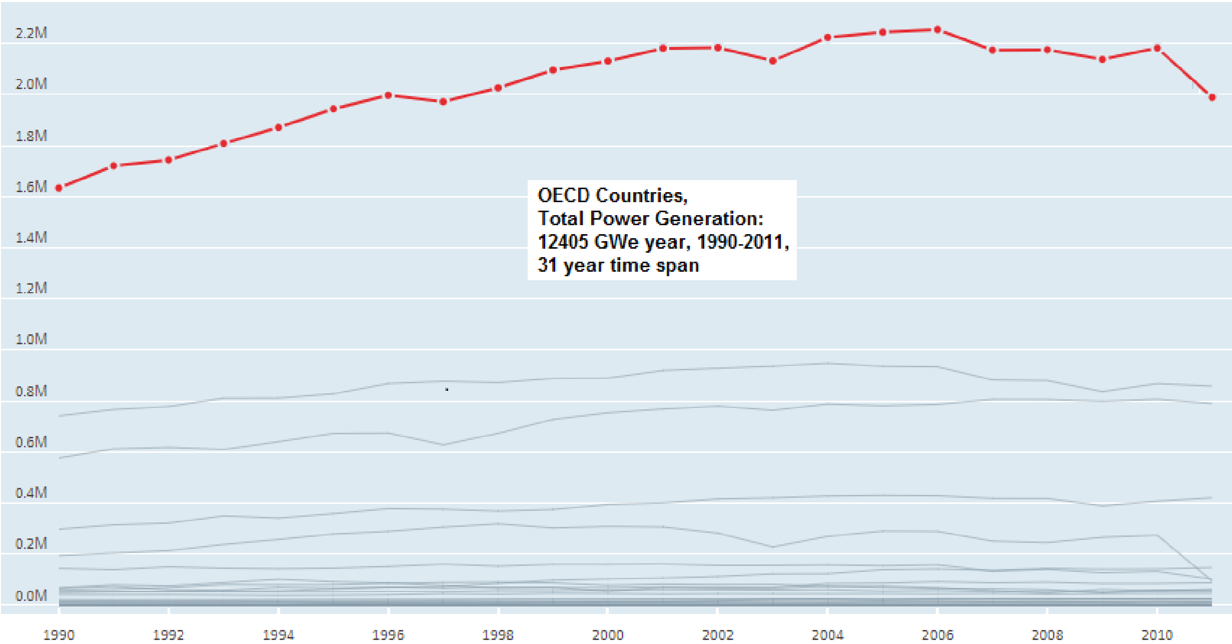

Figure 11: OECD Country Energy Generation, Total Gigawatt Hours for OECD Countries (NEA, [29])

A COMPARISON OF NUCLEAR POWER PLANT ACCIDENTS TO OTHER RISKS

There are two figures that are commonly referenced in nuclear engineering textbooks and classes to promote the safety of the nuclear industry. In fact, this author and many other engineers were taught using these figures for decades. These figures are challenged here.

In Fig. 12 frequency and risk calculations from above are added to existing graphical data to understand the relative safety of nuclear operations as compared to other accidents. Considering the graph, the NRC depicted a range of values for several different accidents with respect to frequencies and the number of fatalities. Rather than extrapolating the entire curve, single points were used to represent the risks associated with the frequency curves. For example, a comprehensive representation would show hurricane risks as a curve, but only a single data point for hurricane risks was extrapolated - a simplified presentation was selected to simplify the graph appearance. Added data for nuclear power plant accidents are presented in their entirety as single data points.

Also, NRC regulatory reactor design recommendations are depicted in Fig. 12 as discussed by Leishear [30] More detail is available in (13, 14, and 18]). Again a question of ethics arises - theoretical frequencies have implied that nuclear reactors are much safer than they are. Risks are appropriate (not frequencies) for accident comparisons. Another observation is that reactor design CDFs and LRFs 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 100 as shown in Fig. 12 (NRC WASH 1400 [22]. This NRC regulatory issue needs to be resolved through changes in regulations, as the NRC requirement cannot be met (Leishear [30]). Since the CDF and LRF differ by a factor of 2, the requirement that they must differ by a factor of 10 or even 100 cannot be met as recommended by NRC documents. Even though conservative calculations by plant operators may meet this requirement, the regulations are in error and demand corrections.

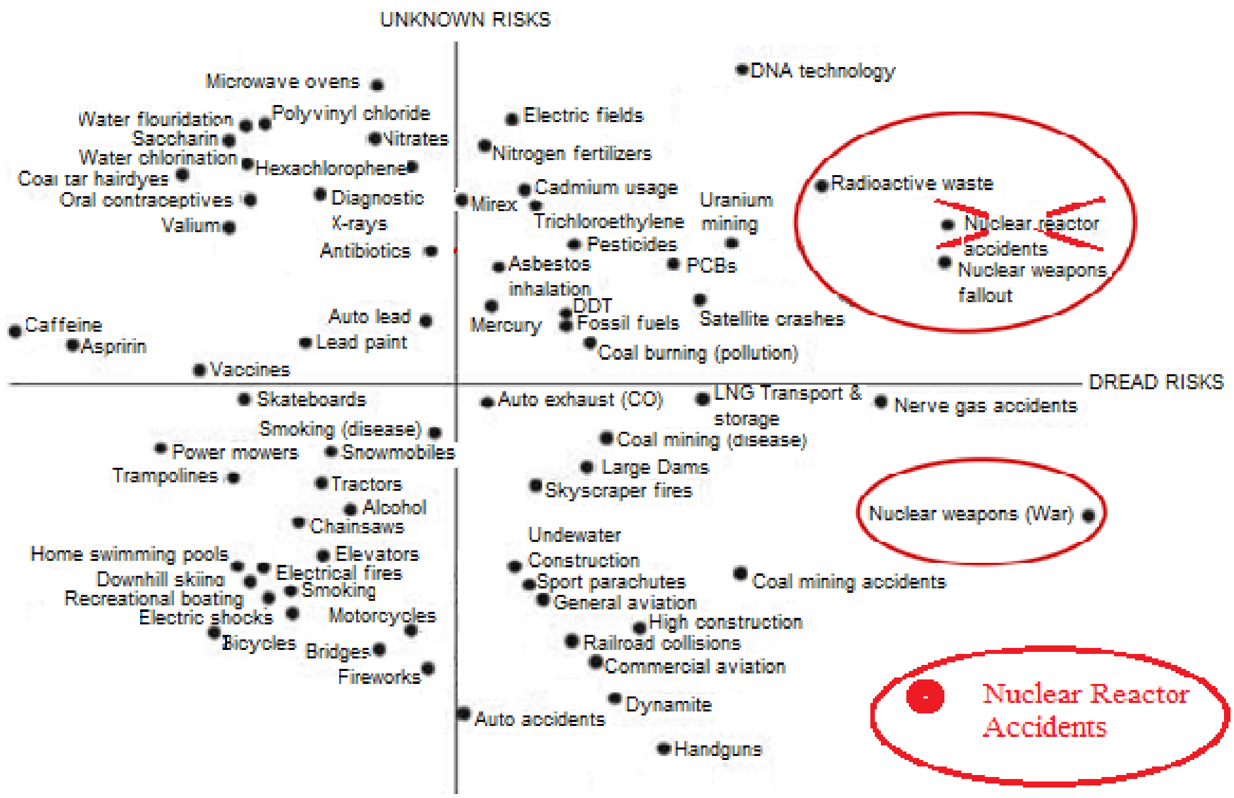

Figure 13: Comparison of Nuclear Power Plant Risks to Other Risks (Adapted from Slovic [31]**)**

Figure 13 presents a comparison of reactor risks to other risks that now changes due to technological explosion advances presented here. 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 power plant explosion effects were unknown at the time that this figure was first created (Slovic, 1987 [32]). "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." Note that Fig. 13 shows that reactors have higher risks than airline travel and explosions, which in turn revises Fig. 12 accordingly – hence the revised figure. Figure 12 is modified to reflect this new understanding of reactor accident explosion risks and a consequent increase in nuclear power plant risks.

Considering the change to Fig. 13, nuclear accidents are one of most dreaded risks of known risks. There are no ethical concerns with respect to this figure since new technology changed this figure. Even so, an understanding of dread risk provides better insight into nuclear accidents. For example, the TMI-2 accident had a zero fatality risk since there were no deaths, but the extraordinary dread risk at the time of the accident sent shock waves throughout the industry. Dread risk about nuclear power plant explosions is still high, and the continuing lack of action by nuclear regulators to address explosion dangers raises ethical concerns as discussed throughout this paper.

AN OVERVIEW OF ETHICS

Ethics has been mentioned and applied to several examples throughout this paper, and to understand ethics first consider the fundamental tenets of ethics. Ethics is the branch of philosophy that explores the nature of moral virtue and evaluates human actions using sets of moral principles and concepts to govern behavior or to conduct activities. After Martinez and Wueste [33] and Cho, et al. [34], and the National Society of Professional Engineers, a discussion of ethics follows, and the relationship between technology and ethics can be summarized by Fig. 14. In this figure, morality and technical, or scientific, information overlap, where reason and logic are used to justify claims of moral truths, i.e., facts are used to determine the right thing to do. Ethics is further divided into three foundational ethical theories, which should ideally converge to the same decision or judgement.

1. Consequences: Consequentialism focuses on the potential short term and long term consequences for the greatest good for the greatest number of people, i.e., an approach to ethics that judges the morality of an action based on the action's impact on the well-being of people and the common good.
2. Rights: Deontology focuses on the act or intent of actions to treat other people with respect since they have inherent value, i.e., an approach to ethics that judges the morality of an action based on the action's adherence to rules or duties.
3. Character: Virtue Ethics focuses on being a responsible person striving for excellence, i.e., an approach to ethics that emphasizes the role of personal character and virtue in determination of morality.

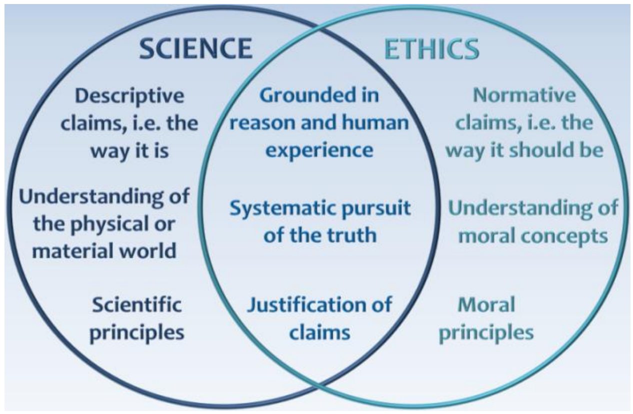

Figure 14: Technology and Ethics (© IOP Publishing. Reproduced with permission. All rights reserved)

Ethics in the Radiology Business

Radiology protection, or radiation protection, is inherent in the nuclear power industry, and "Radiological protection is not only a matter of science, but also ethics," where "the ethical foundations of the system of radiological protection … describes the four core ethical values underpinning the present system: beneficence/non-maleficence, prudence, justice, and dignity. … These core ethical values relate to the principles of radiological protection, namely justification, optimization, and limitation (International Committee on Radiological Protection (ICRP) [35])." Although nuclear power safety is paramount to this research, the ICRP recommendations for ethics are pertinent to this research since the fundamental safety problem for nuclear power plants is the release of radioactive contaminants during nuclear meltdown events, and resolving this problem is fundamental to radiological protection. In fact, much of the information used to understand and apply radiological principles was learned from the radiation exposure of people during nuclear accidents, and safety issues of concern are related to radiological dangers due to radioactive releases.

After Martinez and Wueste [33], ethical principles can be defined as:

4. Beneficence/non-maleficence: Promoting or doing good, avoiding doing harm.
5. Prudence: Practical wisdom, making informed decisions without full knowledge of the scope and consequences of an action, e.g., the extent of explosion damages.
6. Justice: Fairness in the distribution of advantages and disadvantages.
7. Dignity: Treat people with respect/involve stakeholders, the unconditional respect that every person deserves, irrespective of personal attributes or circumstances.

Procedural ethical values include:

8. Accountability: The obligation of individuals or organizations who are in charge of decision making to answer for their actions to all those who are likely to be affected.
9. Transparency: Accessibility of information about the deliberations and decisions concerning potential or on-going activities, and the honesty with which this information is transmitted.
10. Inclusiveness: Ensuring that all those concerned are given the opportunity to participate in discussions, deliberations, and decision making.

Engineering Ethics

Next, consider the ethical responsibilities of engineers who perform research and document their findings through engineering publications. The Code of Ethics for the National Society of Professional Engineers provides guidance, which states that "Engineering is an important and learned profession. As members of this profession, engineers are expected to exhibit the highest standards of honesty and integrity. Engineering has a direct and vital impact on the quality of life for all people. Accordingly, the services provided by engineers"

11. "Require honesty, impartiality, fairness, and equity,"
12. "And must be dedicated to the protection of the public health, safety, and welfare… Engineers, in the fulfillment of their professional duties, shall: Hold paramount the safety, health, and welfare of the public."
13. "Engineers must perform under a standard of professional behavior that requires adherence to the highest principles of ethical conduct."
14. "Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession."

Ethics and This Research

Finally, consider how this discussion of ethics is pertinent to the research at hand. The three theories of ethics, along with ethical principles and ethical values converge to the same conclusions, i.e., actions shall be taken to prevent nuclear power plant explosions, and the limitations of nuclear power plant safety shall be recognized.

Ethical theories:

1. Consequences: There is a potential for a nuclear accident before 2039, and there is a one in two probability of a large scale radioactive release that can explode radioactive dust into the air, which can then disperse as a radioactive dust cloud to travel around the globe as the earth rotates. Radioactive dust travelled from Japan and passed over northern Canada after the blast. Cattle in Northern Ireland are still inedible following contamination by radioactive fallout from Chernobyl dust clouds. Similar blasts can be stopped.
2. Rights: Hundreds of thousands of people have been evacuated from their homes and businesses due to previous nuclear power plant explosions. During the Fukushima evacuation, more than 100 elderly people also perished due to the stresses of relocation efforts. Nearly 100,000 people are still not allowed back into their neighborhoods after 11 years due to radioactive contamination of their homes, land, and businesses. By preventing future explosions, the rights of people through disaster protection are ensured.
3. Character: This research challenges well accepted engineering opinions. To fight uphill against the ingrained beliefs of others is a difficult and stressful process, and undertaking this fight, and not looking the other way, requires great stamina.

As an example of this stamina, this author previously published significant work that bucks normative beliefs, and he clearly understands the stress and difficulties involved. That is, his theory on how fluid transients break piping (including nuclear plant piping) was, and continues to be, an uphill battle. He spent two years writing and rewriting his Master's Thesis – 10 revisions – on this topic until his Thesis advisor was convinced of this work's value. New ideas require hard work to earn acceptance. At the conclusion of that Thesis defense, the author's Adviser stated that this work was the best research that he had ever seen at the University of South Carolina, even though tempers flared on both sides during theoretical progress.

Based on this research, ASME papers (Leishear [36]) were written on the topic of piping failures due to water hammer[26]. This work also resulted in an explanation of why nuclear power plant pipes break due to hundreds of small explosions inside of nuclear reactor piping systems, and also explained why 13 billion dollars per year in water breaks occur across North America alone (Leishear [38]).

The fight for ethics has a personal cost during the fight, but the benefits to others outweigh the personal costs. The personal costs in this example were many tiresome and stressful volunteer hours of defending engineering research to many engineers along the way - myriad hours were lost to these arguments that could have been otherwise spent with family - but the benefits will be the prevention of multi-billion dollar infrastructure expenses by preventing piping failures throughout industry. The explosions research discussed here will require the same rigorous defense to stop nuclear power plant explosions, but loss of life will be prevented. In the words of a rock and roll song by Chumbawamba, "I get knocked down. I get up again. You're never gonna keep me down".

[26] Initial papers were refused publication, and one of the reviewers wrote "Bull****" 23 times as review comments, i.e., the reviewer adamantly disagreed with the new Leishear Stress Theory. Those papers were published after appealing the refusal decision to the Conference Chair. At the Conference, the Conference Chair stated to the engineering audience that this research had no value. Washing away this opinion, subsequent papers on this topic were designated as Honors papers in the ASME, Journal of Pressure Vessel Technology, and ASME published a book on the topic (Leishear [37]). In fact, the term Leishear Stress Theory was coined after this Dynamic Stress Theory research was published by another author in a pop-science engineering magazine. That author claimed that he did not intend plagiarism, but he admitted that the work was not his own. He heard about it, and it sounded good.

Ethical principles:

4. Beneficence/non-maleficence: The primary intent of this research is to help others, where more than 20,000 hours of part time volunteer research were invested over 20 years for water hammer and explosions research, and another 7000 hours of full time research have been voluntarily invested into explosions research. These hours are the equivalent of 13-1/2 years of 40 hour work weeks for unpaid volunteer research to benefit our society.
5. Prudence: This research resulted in the invention of the Leishear Explosion Theory, where new knowledge was created where knowledge did not previously exist.
6. Justice: Since the location of the next nuclear accident cannot be predicted, and radioactive contamination can occur anywhere, these accidents affect people world-wide.
7. Dignity: A primary goal of this specific paper is to engage stakeholders, which include nuclear regulators, nuclear power plant operators, and the public at large – all of whom are affected by the potential for future explosions, which can be stopped.

Procedural ethical values:

8. Accountability: To change this paper to first person. "I am accountable for my actions, and consequently I have an obligation to accurately report the facts as I understand them, and I have a further responsibility to not just report the facts, but to provide interpretations of facts to better serve other people."
9. Transparency: This paper endeavors to clearly present the case to improve nuclear power plant safety.
10. Inclusiveness: This research affects all industrialized countries that operate nuclear power plants, where Nuclear power plants currently operate in 31 countries, and most are in Europe, North America, East Asia, and South Asia. Additionally, all countries throughout the world are potentially affected by radioactive dust clouds. The NRC the DOE have declined opportunities to support this research or to address applicable safety concerns for the U.S. reactor fleet.

Ethical responsibilities of engineers:

11. Dedication to the safety, health, and welfare of the public: Public welfare comes first in this research, and improved safety and health will be the outcomes of this research.
12. Act honorably, responsibly, ethically, and lawfully: Personal accountability and responsibility are the underlying principles of this research.
13. Act with the highest principles of ethical conduct: Engineers are the caretakers of technology, and must act accordingly. Engineers must stand up for what they believe to be right and true to protect those who depend on the skills and competence of engineers, where a primary engineering responsibility is to ensure the safety and well-being of our citizens.
14. Act with honesty, impartiality, fairness, and equity: There is difficulty in acting impartial, and appearing to be impartial, when contradicting the work of earlier researchers or challenging NRC ethics, since ego could trample, or appear to trample, impartiality when expressing one's own thoughts. However, the author has carefully studied and evaluated these earlier works and NRC actions as his research proceeded to ensure that discussions presented here are impartial.

Ethics and Decisions

The principles of ethics demand that the previous understanding of nuclear reactor safety and future preventive actions for power plant explosions must be questioned and corrected. Again changing this paper to first person, I am responsible for my actions, my actions reflect my choices, and I choose to stand against current knowledge to forge an urgently needed change to the future of the nuclear reactor business – explosions can be stopped. My challenge of past theory to prevent death and destruction is a right and just action, and this paper is a written statement of that challenge. I am a dreamer, I see things that can be, and I work hard to make those dreams become fact. Nuclear plant piping explosions can be stopped; nuclear plant building explosions can be stopped; and imminent, unnecessary deaths can be stopped.

Opinions vs. Facts

Even so, an argument can be made that this author's opinion, or engineering judgement, is just one of several different technical opinions on the subject of nuclear reactor safety and power plant explosions. This paper worked to overcome this argument and demonstrate the factual competence of this theory to stop nuclear power plant explosions, and to factually prove that day to day operational safety in the nuclear power business is far less than previously endorsed. As an engineering axiom, once a problem is clearly understood that problem can be corrected, and the explosions that are discussed here can be prevented. The facts are clear that lives are at stake, major environmental damages are at stake, power plant destruction is at stake, and these problems can be stopped.

AN ETHICAL DILEMMA IN THE NUCLEAR INDUSTRY

All in all, there are many new questions that relate to nuclear power plant safety and ethics. Previous graphic descriptions used to demonstrate nuclear industry safety are incorrect due to explosions research discussed here that sharply changed the understanding of reactor safety. Additionally, publicized, misleading nuclear data graphics challenge 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 when citizens are not aware of the actual safety conditions of the reactor fleet.

Findings presented here constitute new safety risks, some of which result in ethical issues and some of which do not. 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 level of acceptance applies to these newly identified, but comparable, risks 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. Safety risks, in terms of fatalities, are comparable to other industries, but the dread risk is much higher for nuclear industries when compared to other energy industries. Even so, these explosion risks are inherent in the present operations of nuclear power plants, and as such a reasonable case can be made that the findings of this work endorse continuing safe operations. A primary goal of this specific publication is to change NRC and DOE actions to make our country safer through safer nuclear plants.

FUTURE RESEARCH

Future research to model the explosions at TMI-2 and Hamaoka is planned as continuing volunteer research. Government grants are blocked on all fronts. The NRC suggested the National Science Foundation, who, along with the Small Business Administration, refused a grant and suggested the Department of Energy (DOE)[27]. The DOE recently dismissed a research grant proposal for research on "The Autoignition of Nuclear Power Plant Explosions" without consideration by stating that preventing nuclear power plant explosions does not "propose innovative technology development to improve the capability of the existing fleet". They made this statement after previously endorsing the Abstract for this same research. The DOE refused to clarify this statement, even though I informed them in a 5/5/2020 email that this statement is "patently false", and that "we can move forward together to make our country safer by improving nuclear power plant safety**.** … How can this work not be important to the DOE? **…** Actively preventing this research could protect previous false government reports.**"** The DOE also refuses to answer emails that request that they, "Please answer the question of why preventing nuclear power plant explosions does not "propose innovative technology development to improve the capability of the existing fleet". I have asked this question several times and the basic answer has repeatedly been that it does not comply because it does not comply. My extraordinary efforts to save lives merit an answer". Not only do the stewards of this grant request refuse to discuss these issues, but the Office of the Secretary of Energy refuses to discuss these important reactor safety issues as well.

In other words, DOE not only refused to support this research, but made false statements to actively interfere with government funding for this research, and refuses to explain their actions. Together, these DOE actions constitute a potential cover up of explosion dangers to the public, and also constitute a clear violation of the DOE mission "to ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions". This ground breaking research is transformative in the nuclear industry.

These DOE issues are under review and evaluation by the DOE Office of the Inspector General, following a 5/28/202 Allegation, titled "DOE Cover Up of Explosion Dangers in U.S. Nuclear Power Plants," [39]. This

[27] Explosion research grants were also refused by other government agencies. The Bureau of Science and Environmental Engineering refused grant support since there were more important issues than understanding the explosion cause of offshore oil explosions like the Gulf Oil Spill [41], where the explosion cause is similar to nuclear plant explosions. The Pipeline and Hazardous Materials Safety Administration (PHMSA) turned down a grant request to investigate gas pipeline explosions by monitoring explosions. However, PHMSA graciously responded to an email titled, "PHMSA Kills People", and explained that the money was gone, but their staff has been of great assistance in providing information to investigate gas pipeline explosions, which are essentially the same as nuclear plant explosions.

Allegation opened with the statement that "The DOE, Idaho Operations Office improperly, unethically, and dishonestly dismissed a research grant proposal to prevent explosions in nuclear power plants, and this decision will directly result in loss of life and disastrous environmental damages, i.e., this DOE decision can kill people and spew radioactive contamination across U.S. property." A detailed discussion in this Allegation includes a draft of this paper.

Is there an ethical conflict of interest concerning this author's comments about DOE and NRC? This question is important to the writings presented here. One could opine that an interest to earn profit drives this discussion, which is not the case. While earning money is certainly a benefit, the planned use of grant funding would be to support future experimental research to better understand and prevent explosions. As a matter of fact, the initial Abstract for this research included experimental work, but DOE nonfeasance cancelled that part of the research, where Merriam-Webster defines nonfeasance as the failure or omission to do something that should be done or especially something that one is under a duty or obligation to do. DOE refused to answer the simple question of how payments would be made for grant research, and an explosives range contractor interested in performing the explosions withdrew from the research until payment procedures are known and a first contract is received and performed. The grant proposal Abstract was then revised to keep the intent of explosion prevention the same, but explosion tests were dropped from consideration. Much personal money has been invested into this research to make our country safer, but paying contractors out of pocket to perform explosions research is out of the question. Effectively any experimental research was blocked by DOE, but computer modeling as requested in the dismissed grant proposal will be performed by this author to make our country safer.

As volunteer research continues, the fight to do the next right thing continues for the sole purpose of stopping death and destruction. Two more years of planned voluntary research, at an additional personal cost of more than $70,000 is well worth the effort. "I get knocked down. I get up again. You're never gonna keep me down". Research continues regardless of funding.

CONCLUSIONS

Contrary to previous research by others, significant claims about nuclear power plant safety problems 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. There is an imminent risk of another nuclear accident. A conservative, or safer, model predicts a reactor core meltdown in 2039, and a non-conservative model predicts a meltdown in 2061. The 2039 meltdown prediction is endorsed here, and there is a one in two probability of a large radioactive release at that time.
2. Even so, reactor shutdowns and new technology may affect these estimates, since an important assumption is that reactor operations will be similar in the future. Whether future predictions are affected or not, meltdowns and explosions can happen at any time, where actions to minimize the possibility of explosions should be implemented.
3. Frequency predictions for nuclear reactor accidents were previously estimated to be once in 50,000 years for individual reactor designs and about once in 200 years for the U.S. reactor fleet (Fig. 3), but consideration of the TMI-2, Chernobyl, and Fukushima accidents leads to a frequency prediction for a nuclear reactor meltdown of once every 28 years - a remarkable difference.
4. Every other meltdown accident - every 55 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 misleading publications.
6. Fluid transients are the common cause of nearly all nuclear power plant explosions, where hydrogen is compressed in piping systems due to pump and valve operations, which in turn heats hydrogen to autoignite explosions. The complex processes to do so in nuclear power plants are described by the Leishear Explosion Theory.
7. A discussion of ethics was presented to consider the ethics of this research, the ethics of some previous research, and the ethics of government agencies that thwart this research.
8. What engineers ethically think as they work is as important as the work that they do since lives are often at stake.
9. Ethical decisions can be costly to engineers, and the costs to this author are discussed by way of example.
10. Acting ethically frequently has a cost, but the cost is worth the effort.
11. Some previous publications are grossly inadequate, where skewed data has incorrectly led people to believe that nuclear reactors were remarkably safe, when they are not.

12. The risks of future accidents can be minimized if explosion prevention is better incorporated into nuclear power plant operations.
13. The U.S. NRC and the DOE refuse to act on explosion findings, and the actions of these organizations endanger public safety in general, the lives of our citizens in particular, and the environment around us.

Since these risks have not been addressed in other studies, government publications and 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 a 1979 explosion rather than a fire, and Fukushima reports do not yet acknowledge the autoignition cause of explosions that fired radioactive dust into the air and around the earth. More importantly, prior to every meltdown and every explosion, governing authorities believed and publicly claimed that accidents were impossible, which is a common thread that connects all nuclear accidents. Until and unless explosion risks are acknowledged and addressed, these risks are not likely to be resolved, and the probability of a near-term, preventable explosion due to a 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? The nuclear industry has stringent safety regulations (NRC [40]) and, all in all, the nuclear industry is as safe as other industries, but the nuclear industry is not as safe as it has been claimed to be and current regulations are inadequate with respect to new and proven explosion theory. Nuclear power plant safety can be improved to save lives, property, and the environment.

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APPENDIX B

THERMAL FLUID TRANSIENTS CAUSE PIPING FAILURES

AND NUCLEAR POWER PLANT FIRES AND EXPLOSIONS

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ABSTRACT

Explosive new technology has been invented to understand the explosions following the Fukushima Daiichi reactor meltdowns, a 705 pound hydrogen fire following the Three Mile Island (TMI) meltdown, and gas accumulation events that crack pipes in nuclear power plants. Using the same research results, corrective actions will be determined to minimize 250,000 North American piping failures per year. A preliminary cost estimate for research is $1,500,000. The outcomes will be remarkable as new theory is further proven, and corrective actions are resolved and demonstrated. Dr. Leishear invested many thousands of hours of volunteer research and personally invested nearly a hundred thousand dollars to improve safety at U.S. nuclear power plants and cut costs for U.S industries.

Who is the proposer?

Robert A. Leishear, Ph.D., P.E. is the proposer and inventor of applicable theories. He wrote more than 70 publications that include a book on "Fluid Mechanics, Water Hammer, Dynamic Stresses, and Piping Design", 2013, ASME Press. His research to date on these new theories is summarized in, "Fires and Explosions in Nuclear Power Plants", 2018, American Nuclear Society, and "Water Main Failures Due to Water Hammer – A Billion Dollar a Year Problem", 2018, Empowering Pumps Magazine" (Leishear [1-11]).

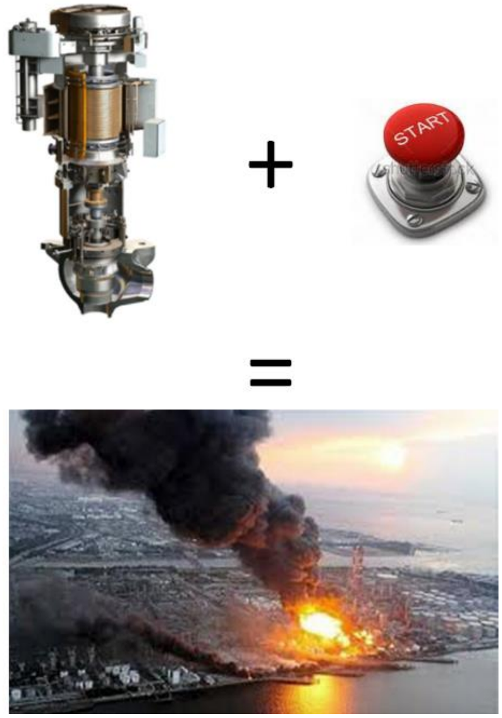
To prepare for this research, Dr. Leishear has studied full time for the past two years. In this time, he has completed all of the necessary classes to earn a Ph.D. in Nuclear Engineering, where he already completed a Ph.D. in Mechanical Engineering. During this time, he has also completed many computer modeling classes in reactor physics, reactor operations, fluid mechanics, and structural mechanics. Together with his extensive career as a project engineer and research engineer at Savannah River National laboratory, he is ready to start this research project, which will be documented in Conference and Journal publications, along with documentation in a Nuclear Engineering Ph.D. Dissertation at the University of South Carolina.

What you propose to do and how you propose to do it (500 words minimum)?

There are three different new theories applicable to this research, which basically describe the major tasks to be researched. These theories overlap each other, but form a cohesive body of knowledge to understand piping failures, explosions and fires in nuclear facility systems, where the results will be applicable to other industries as well.

Research for these three theories is summarized as follows.

1. **Theory #1**: Flammable gasses inside piping compress, heat up, and self-ignite to cause fires and explosions in nuclear power plants and off-shore oil rigs, such as the Gulf Oil Spill (Explosions: A Fresh Look a t Chernobyl, Three Mile Island, the Gulf Oil Spill, and Fukushima Daiichi, 2013, Mensa World Journal). Accordingly, NRC regulations require changes, where the rules for nuclear reactor safety analyses do not account for these new findings. Note that the Fukushima explosions could have been prevented by venting flammable gasses before starting pumps to refill the reactors, where Dr. Leishear immediately recognized that the pumps were restarted when the explosions were televised (See Figure 1). That is, the theory had already been published, but had not yet been accepted, and is still not yet widely accepted. This research is tailored to ensure acceptance of this important theory to improve emergency response in the event of an unlikely meltdown accident. To this day, NRC and IAEA reports are inadequate with respect to their descriptions and analyses of nuclear reactor accidents, where the ignition mechanism of fires and explosions has not been accepted.



2.

3.

Figure 1: Ignition of Nuclear Reactor Plant Fires and Explosions

Research: Perform computer simulations of the Three Mile Island meltdown accident, with the first ever model of the hydrogen fire. TMI was selected due to extensive, available technical data that can be used as a basis for modeling. Also, the fire was discussed in a 2013 ASME Magazine article titled, “From Water Hammer to Ignition - The Spark that Ignited Three Mile Island Burst from a Safety Valve. Models will include:

a. PARCS models of the reactor physics of TMI at the time of the accident (Training completed).
b. POLARIS models to validate PARCS model reactor physics at the time of the accident (Training completed).
c. ORIGEN models for minimal fuel depletion at the time of the accident (Training completed).
d. RELAP5 models to evaluate TMI thermal hydraulics at the time of the accident (Training completed).
e. FRAPCON models of hydrogen generation during normal operations.
f. RELAP5 models to evaluate TMI thermal hydraulics during the accident (Training completed).
g. FRAPTRAN models to evaluate TMI hydrogen generation during the accident.
h. MELCOR models for the meltdown conditions during the accident.
i. FLUENT models of hydrogen ignition in reactor piping and spark ignition of the reactor building hydrogen fire (Training completed).

4. **Theory #2:** Gas accumulation events have occurred in nuclear reactors since the 1950,s, but these events are actually small fires and explosions of radiolytically generated hydrogen, which is generated by nuclear reactors. Hundreds of small fires and explosions in nuclear reactor systems have been incorrectly assumed to be water hammer incidents. This research will further prove this important fact to improve reactor safety, and prevent further reactor piping damages.
   Research: Perform computer simulations of a Hamaoka piping explosion that shredded a 6 inch diameter, steel pipe like a paper firecracker, where this explosion was similar to smaller explosions that have been misdiagnosed as gas accumulation events in U.S. reactor plants (See Figure 2). Models will include:
   a. FLUENT models of combustion ignition during the Hamaoka accident. This accident was selected for investigation since nearly all of the required technical details are available to set up FLUENT models (Training completed).

b. FLUENT models of gas release to the atmosphere, which will provide insight into the TMI hydrogen fire (Training completed).
c. AUTODYNE models to describe the massive deformation of the piping during this Hamaoka explosion (Training completed).
d. RELAP5 models of typical reactor plant piping additions that can be used to prevent gas accumulation accidents. The TMI models will be used to demonstrate proof of principle for corrective actions for other reactor designs.

Figure 2: Hamaoka Nuclear Power Plant Piping Explosion

5. **Theory #3:** Dynamic load factors (DLF's) magnify piping stresses to cause piping fatigue fractures. DLF Theory will prevent future piping failures in nuclear plants. In parallel, this theory will result in the reduction of hundreds of thousands of underground water main failures throughout the industrialized world, as well as piping failures throughout many other industries.
   Research: DLF theory was invented and proven in Dr. Leishear's ASME text, but there is additional research required to fully implement that theory for piping failures in reactor systems and elsewhere. In fact, the results of this research are intended to support a new international Consensus Standard, "ASME B31D, Design of Piping Systems for Dynamic Loads from Fluid Transients", where Dr. Leishear is the ASME Project Manager, writer, and editor for this in-process publication. Balloting continues, but the information to be gleaned from this research is essential for improvements to this Standard.
   a. Perform FLUENT computer simulations of fluid transients and combustion for the ignition of flammable gasses during operations, i.e., reflected waves, gas accumulation, and valve closure rate effects on water hammer and combustion (Training completed).
   b. Perform ANSYS Structural computer simulations to determine DLF's due to incident and reflected pressure waves for different piping sizes (Training completed).
   c. Compare models to previous experimental results, where previous research (Leishear) stopped hundreds of piping failures that occurred over forty years at Savannah River Site in million gallon storage tanks, which contain radioactive liquid waste. A typical cooling coil pipe failure is shown in Figure 3. DOE cost savings were estimated at $15,000,000, and the Facility Evaluation Board noted that this work was "Good Practice".
   d. Determine damping effects on DLF's near the yield strength.
   e. Determine DLF's during plastic deformations

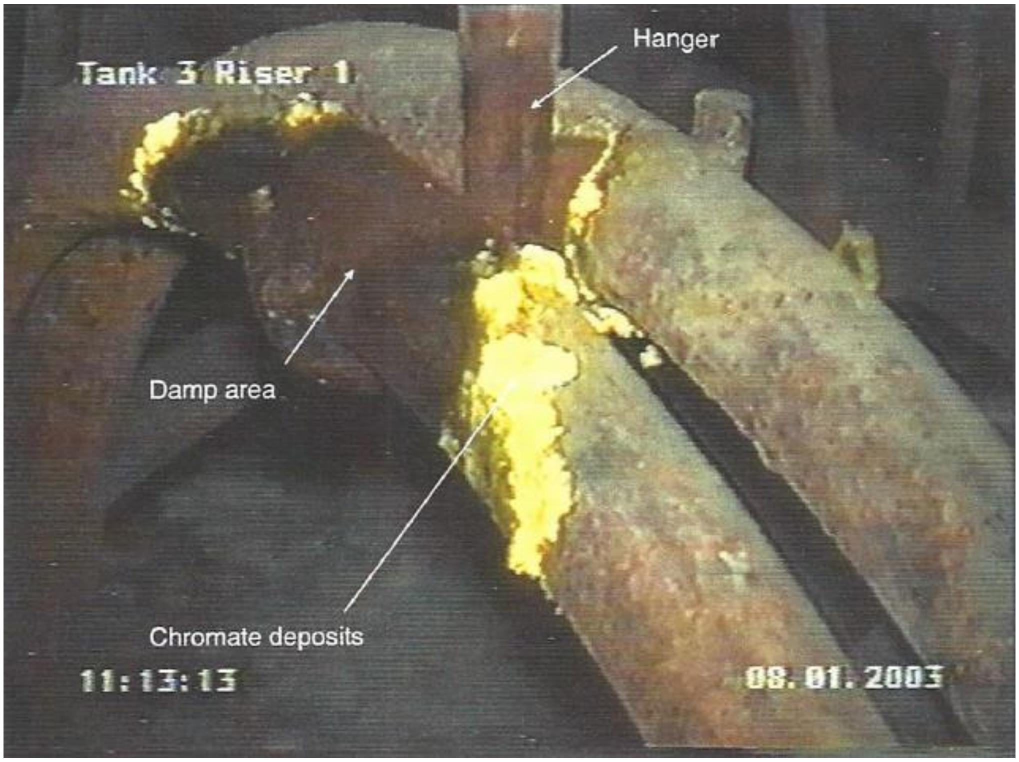


Figure 3: Typical Savannah River Site Cooling Coil Failure, Radioactive Liquid Waste Storage Tank

6. **Experimental Validation:** Perform scaled testing as proof of theory for flammable gas autoignition and gas compression in piping. Testing will consist of:
    a. Perform scale models of piping explosions, where exploding pipes vary in diameter from 1 inch to 6 inches (See Figure 4).
    b. Perform scale models to experimentally validate gas accumulation FLUENT models (Not shown).

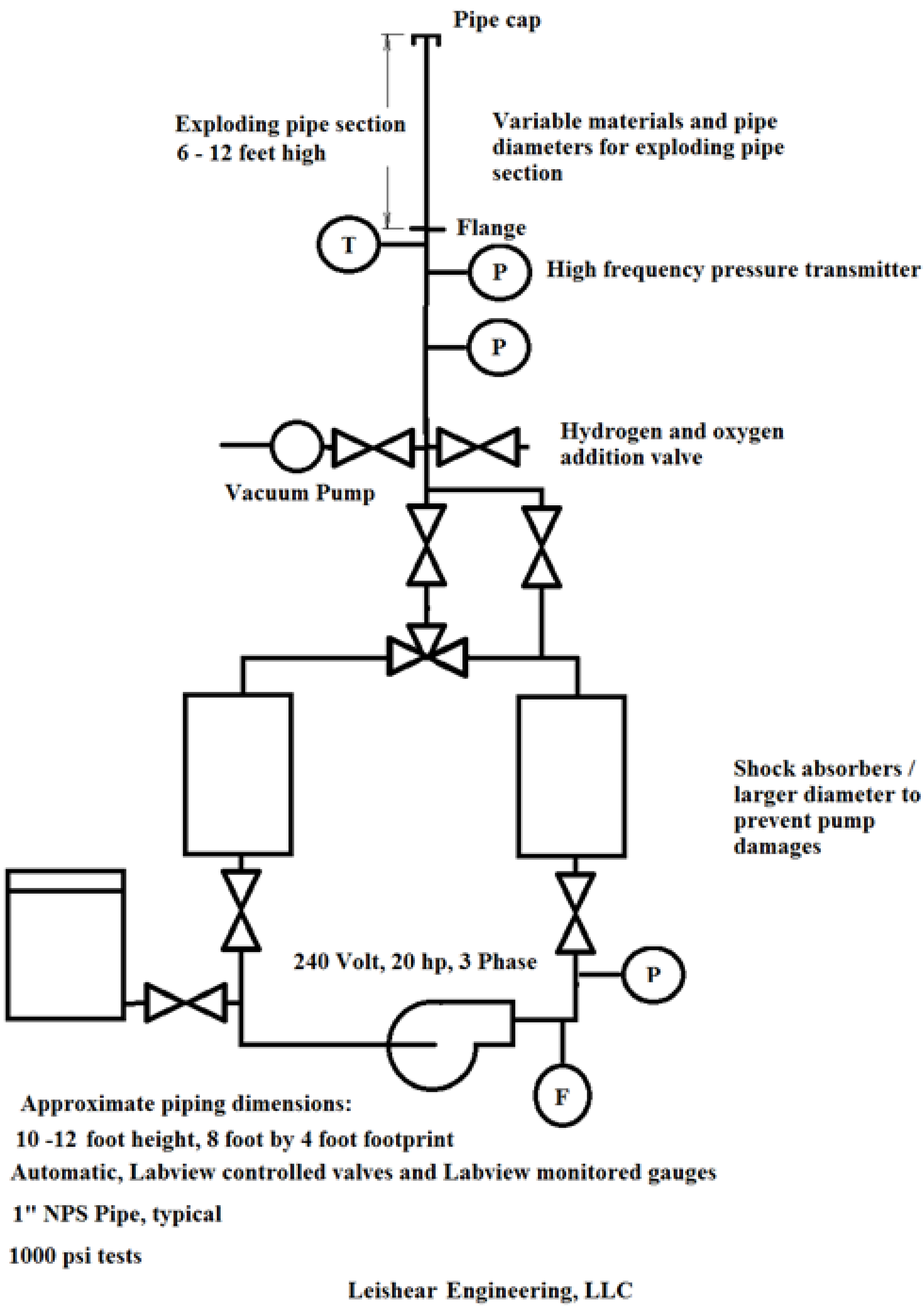


Figure 4: Tentative Explosions Test Schematic

How does the technology meet the DOE mission (http://energy.gov/mission)?

This research will yield paradigm shifts in technology to prevent nuclear power plant fires and explosions, and will prevent world-wide piping failures. These goals advance the mission of the Energy Department by yielding major infrastructure improvements, and improving nuclear operations through transformative science and technology solutions. That is, new theories were invented that benefit the DOE, where safety of commercial nuclear reactor operations will improve, nuclear reactor operating costs will markedly decrease, and billions of dollars in other U.S. industries will be saved.

Why is it beneficial to the DOE?

Damages to DOE facility piping will be prevented, in addition to the prevention of nuclear reactor fires and explosions. In fact, DOE has already received cost savings from this research, where $15,000,000 in cost savings were realized for the SRS, noted above. *Additionally, in a 2017 project by Leishear Engineering, LLC proved that 53 underground piping failures that occurred over 22 years in a critical fire protection system were caused by water hammer, where these failures were incorrectly believed to be caused by corrosion. Fire alarms were set off three times a week for decades as well, and water hammer was the cause of the fire alarms. Some corrective actions were taken, and the fire alarms were nearly eliminated.*

The validity of the theories that underpin this research is clearly evident through experimental proof, but the additional research requested in this proposal will enable widespread application of corrective action methods. In short, this work is important to national safety and cost effective operations of American industry. Nuclear reactor building explosions can be stopped during unlikely meltdown accidents! Ongoing nuclear reactor piping explosions can be stopped! Plant operators currently do not realize that explosions rather than water hammer events are occurring! Billions of dollars in industrial piping failures can be stopped! These world-wide problems can be stopped! These one-man theories are already here to solve these problems, and this research can provide the corrective actions!

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APPENDIX C

PROJECT SUMMARY / ABSTRACT, DE-FOA-0001817, ARD-20-21608

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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.