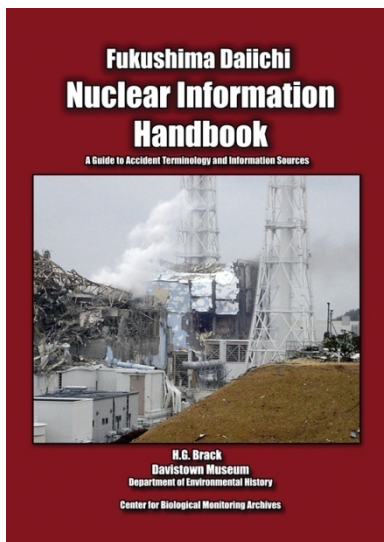


Publication Announcement



The Davistown Museum Department of Environmental History announces the publication of *Fukushima Daiichi: Nuclear Information Handbook*. Published as a result of the need to document and understand the results of the 2011 Japanese disaster, the *Handbook* is a clearly written guide to nuclear accidents for first responders, emergency management personnel, media, and concerned laypersons. It is an essential reference for evaluating the significance, impact, and emissions pathways of any nuclear accident. Currently available from Amazon.com in paperback (\$24), the *Handbook* will also be published in Kindle eBook format. An introduction to the text and its subject index guide can be found at www.davistownmuseum.org/publications.html#Handbook.

The *Handbook* begins with a detailed description of the seven ongoing interrelated nuclear accidents at the Fukushima Daiichi complex and continues with easy-to-understand explanations of the reporting units, biologically significant radioisotopes, contamination levels of concern, protection action guidelines, and pathways of any nuclear accident. It also includes information not available from other sources, such as classified U.S. spent fuel inventories, baseline data pertaining to nuclear weapons fallout and other nuclear accident point sources, a comprehensive Chernobyl fallout database, and confidential documents pertaining to fuel cladding failures in aging nuclear reactors.

Handbook highlights include:

- The amount of radiation released from the 4,368 fuel assemblies that suffered loss of cooling at the Fukushima Daiichi complex appears to be significantly larger than that for Chernobyl. Luckily, prevailing winds transported a large percentage of aerial emissions over the Pacific Ocean.
- The design defects in the GE-designed boiling water reactors, 35 of which are located in the US, played a key role in this multiple interlocking meltdown event (MIME). These defects include an elevated spent fuel pool located within the secondary containment of the reactor building and vulnerable backup diesel generators, control rod insertion equipment, and steam/gas venting systems.
- The MIME at Fukushima Daiichi was a two-stage accident, with hydrogen explosion and zirconium fuel cladding fire-associated releases occurring in the first 10 days of the accident.
- The second stage of the accident involves ongoing chronic releases of radioactive steam and water, which will continue until a safe melted fuel storage facility with a closed loop cooling system is constructed at or near the Fukushima Daiichi complex.
- Over two million fuel assemblies now reside in vulnerable spent fuel pools at 442 aging reactors and weapons production facilities throughout the world. Many of these share the same subprime design of the reactors and spent fuel pools at the Fukushima Daiichi accident site.

The safety issues highlighted by the accidents in Japan should be the subject of informed debate among public safety officials and concerned citizens, especially those living within a 20-mile radius and/or downwind from any operating nuclear reactor, particularly at-risk-for-failure boiling water reactors.

Tokyo Electric Power Company (TEPCO) and Japanese government workers at the Japanese complex have made a heroic effort in the improvised manual cooling of the melted fuel assemblies, thus preventing further catastrophic hydrogen explosion-propelled releases of radiation. Unfortunately, reconstruction of a safe closed-loop cooling system, which would end ongoing chronic emissions, is not possible at the seven damaged facilities at Fukushima Daiichi. The design, implementation, and construction of storage facilities for accident-derived melted fuel and radioactive water may take years or even decades.

The *Fukushima Daiichi: Nuclear Information Handbook* is an essential reference for anybody who may in the future have to evaluate the significance, impact, and emissions pathways of any nuclear accident, including those that may occur at the 35 at-risk, aging boiling water reactors located in the United States.

Request for Public Service Announcement

The Davistown Museum announces publication of *Fukushima Daiichi: Nuclear Information Handbook*, now available from Amazon.com in paperback (\$24) and soon in Kindle eBook format. Published as a result of the need to document and understand the results of the 2011 Japanese disaster, the *Handbook* is a clearly written guide to nuclear accidents for first responders, emergency management personnel, media, and concerned laypersons. It is an essential reference for evaluating the significance, impact, and emissions pathways of any nuclear accident at one or more of the world's 442 aging nuclear reactors and weapons production sites. Two million fuel assemblies are currently stored in accident-prone spent fuel pools throughout the world; 4,368 of them are currently involved in the ongoing multiple interlocking meltdown event (MIME) in Japan. In the post-Fukushima Daiichi nuclear accident era, it is possible that the next loss-of-reactor-coolant accident (LORCA) could occur at one of the United States 35 high-risk "subprime GE-designed" boiling water reactors.

Would your media organization please make a public service announcement highlighting the availability of this 390-page document? A more complete description of this *Handbook* is contained in the Publication Announcement, which, if not attached to this message, is available at www.davistownmuseum.org. A complete listing of all Davistown Museum publications is also available on our website.

Persons seeking a review copy of this publication should contact curator@davistownmuseum.org.

Media Memo

The ongoing loss-of-coolant accidents (LOCAs) at three reactors and four spent fuel pools at the Fukushima Daiichi nuclear complex in Japan, and the resulting publication of *Fukushima Daiichi: Nuclear Information Handbook*, highlight a number of nuclear safety issues, which have not received much attention in American, Japanese, and European media.

- Fuel cladding failures in aging reactors make “scrams” or emergency shutdowns more difficult. Fuel rod and steam tube distortions and fuel pellet spillage may hinder the reinsertion of control rods or impact their effectiveness in emergency situations. Aging fuel assemblies and incomplete control rod insertion may have played a role in the ongoing Fukushima Daiichi multiple interlocking meltdown event (MIME). See Section IX of the *Nuclear Information Handbook* for an extensive description of fuel cladding failures at the Maine Yankee Atomic Power Company.
- The Fukushima Daiichi disaster suggests US boiling water reactors are much more susceptible to loss-of-coolant boiling water accidents than are more robustly designed pressurized water reactors. The design defects in the GE-manufactured boiling water reactors at Fukushima Daiichi highlight similar defects in 35 aging at-risk US boiling reactors, including:
 - location of an elevated spent fuel pool next to the reactor vessel and within the secondary containment building
 - location of a steam collection “torus” under, rather than within, the primary containment vessel making it more vulnerable to hydrogen explosions
 - lack of secondary backups to the backup diesel generators, which failed at Fukushima Daiichi
 - location of vulnerable hydraulic control rod insertion equipment under the reactor vessel rather than as gravity-fed (in emergencies) equipment on top of the reactor vessel
 - poorly designed hydrogen gas venting system prone to failure in the event of the failure of the backup diesel generators
- See Section I of the *Nuclear Information Handbook* for a more detailed description of the design flaws at the Fukushima Daiichi complex
- The LOCAs at the four Fukushima Daiichi spent fuel pools, which contained 2,871 spent fuel assemblies, highlight the inherent dangers of storing all spent fuel in spent fuel pools. After eight to ten years of cooling, fuel assemblies can be much more safely stored in independent spent fuel storage installations (ISFSIs), only a few of which have been constructed at US reactor sites.
- Fuel assembly failures and LOCAs highlight the difficulty of decommissioning any type of nuclear reactor after fuel cladding failures or meltdown events. Fuel pellets from damaged assemblies contaminate reactor water supplies and the reactor vessel itself. These pellets, if intact, may be vacuumed and moved to a spent fuel pool or remain in the reactor vessel as high-level waste. More frequently, spilled fuel pellets are broken into tiny particles and contaminate reactor water systems, making decommissioning more dangerous and more expensive.
- The hydrogen explosions at Fukushima Daiichi highlight the obsolescence of NRC evacuation zones (plume inhalation, 10 mile radius; plume deposition, 50 mile radius). As occurred at Chernobyl, plume dispersal and contamination deposition are highly correlated with wind direction, wind speed, and rainfall events. The accident-derived super hot plume zones (\pm first two hours of emissions) can extend 30 miles from a quick release accident accompanied by 15 mile per hour winds; ground deposition of Cs-137 in excess of 37,000 Bq/m² can extend hundreds of miles or more from an accident site and is closely associated with rainfall events. Only if there are calm or very low wind speeds would accident-derived super hot zones extend evenly around a reactor experiencing a meltdown event.

It is hoped that the ongoing accidents at the Fukushima Daiichi complex will further discussions and informed debate about the dangers of the world’s aging boiling water and other obsolete reactor designs.

Elevated Risk Zones

at United States Boiling Water Reactors Emergency Preparedness Notice for First Responders

The recent series of nuclear accidents at the Fukushima Daiichi complex in Japan (seven multiple interlocking meltdown events - MIME) have opened a window of opportunity for examining safety issues pertaining to boiling water reactors. Fuel cladding failure and the resulting steam tube deformation and fuel pellet spillage has long been a concern at aging pressurized water and boiling water reactors (Figure 1; also see Section IX of the *Nuclear Information Handbook*). Difficulties in reinserting control rods at Fukushima Daiichi after the March 11th earthquake due to fuel assembly deformation may have played a role in the ensuing meltdown events. The accident in Japan highlights the design flaws that characterize the 35 boiling water reactors situated in the United States (Figure 2). These include:

- An elevated spent fuel pool located adjacent to and above the reactor vessel and **within** the secondary containment structure.
- Vulnerable backup diesel generators, which lack further reliable backup electrical generating capacity.
- Vulnerable fuel rod insertion equipment located below, rather than above the reactor vessel.
- An improperly located steam generation “torus” **located outside of and underneath** the primary reactor vessel containment.
- A hydrogen gas venting system for the torus, which is dependent on the backup diesel generators for venting the gas generated by a loss-of-coolant accident (See *Nuclear Information Handbook* section I).

These design defects in boiling water reactors provide the basis for elevated accident risk assessments for communities located near and downwind from operating reactors. In particular, both the Chernobyl accident and the Fukushima Daiichi disaster graphically illustrate the inadequacy and irrelevance of US NRC 10-mile emergency planning radius and the 50-mile ingestion pathway emergency planning zone (EPZ) radius. Updated emergency preparedness guidelines should include the following:

- **The super hot plume zone:** Two hour duration; 30-miles in the downwind direction of plume movement based on a 15 mph wind and the presence of intensely radioactive short-lived isotopes such as Xe-137 (1/2 T = 3.81 m; daughter product is Cs-137), I-132 (1/2 T = 2.3 h), I-133 (1/2 T = 2.8 h), Te-129 (1/2 T = 69.6 m), and Te-131 (1/2 T = 25 m). This zone requires total evacuation or use of self-contained breathing apparatus.
- **The hot plume zone:** Thirty days duration; 300-miles in the downwind direction of plume movement. In the event of a serious accident, this zone is associated with Xe-135 (1/2 T = 9.14 h), Ce-143 (1/2 T = 33 h), Mo-99 (1/2 T = 67 h), Te-132 (1/2 T = 78 h), Np-239 (1/2 T = 2.35 d; daughter product is Pu-239), Te-132 (1/2 T = 3.2 d), and Sb-127 (1/2 T = 3.85 d). The indicator isotopes I-131 and Cs-137 will dominate hot plume zone exposure after decay of the shorter-lived isotopes.
- **The ingestion plume zone:** 1,500-miles in the prevailing wind direction of plume movement. During the first thirty days, I-131 (1/2 T = 8 d) will join Cs-137 as one of the most important ingestion pathway isotopes. Significant exposure to Cs-137 and other long-lived isotopes will continue for a century or longer in fallout zones that can have contamination ranging from thousands to millions of becquerels of Cs-137 per m² depending on rainfall events and wind direction during plume passage (Figure 3).

The duration of super hot plume zone radioactivity is graphically illustrated by the rapid rise and fall of ambient radiation levels outside of the Fukushima Daiichi facility following the hydrogen explosions and fires during the first ten days (stage 1) of the accident sequence (Figure 4). Residents living downwind from an accident at a nuclear generating facility, especially including **at-risk boiling water reactors**, should reference ground deposition of biologically significant radioisotopes in Skutskar, Sweden, located approximately 600 miles northwest of the Chernobyl accident site (Figure 5). An accident at the Pilgrim Nuclear Generating Station or any other boiling water reactor could result in the deposition of similar levels of radioactivity 500 miles or more from the accident site depending on weather conditions and wind directions. Current NRC EPZ guidelines are totally irrelevant.

The figures below are reprinted from *Fukushima Daiichi: Nuclear Information Handbook: A Guide to Accident Terminology and Information Sources*.

Figure 1. Maine Yankee Atomic Power Company. (April 16, 1998). Appendix A: Spent fuel and other radioactive material stored in the Maine Yankee spent fuel pool. MYPS-101, Rev. 0. Wiscasset, ME. This inventory contains the following information: Out of 1,434 spent fuel assemblies now contained in the spent fuel pool, at least 15% are nonstandard and include the following:

- 66 fuel assemblies with “confirmed failure”
- 10 are consolidated or otherwise damaged
- 50 exhibit “physical damage”
- 18 have fuel rods replaced
- 80 have hollow rods (the present location of the spent fuel originally in these rods is not indicated in this inventory)
- 1 fuel rod is cemented into a pipe
- 1 fuel rod is stuck in a conduit
- 1 fuel rod was removed during a “1992 disposal campaign”
- In addition to this inventory of fuel assemblies in the spent fuel pool, this report indicates five filters “determined to be unsuitable for shipment due to dose rates” are in the spent fuel pool and contain loose fuel pellets derived from vacuuming up the debris released during the failure of the 66 fuel assemblies
- Numerous other filters are within the fuel pool and also contain fuel pellets but as of 1998 the number of these is not known
- 61 additional filters are contained in trash baskets in the spent fuel pool which also contain solid wastes from thermal shield positioning pin repairs; these filters may also contain spent fuel pellets derived from the fuel cladding failure accidents at MYAPC

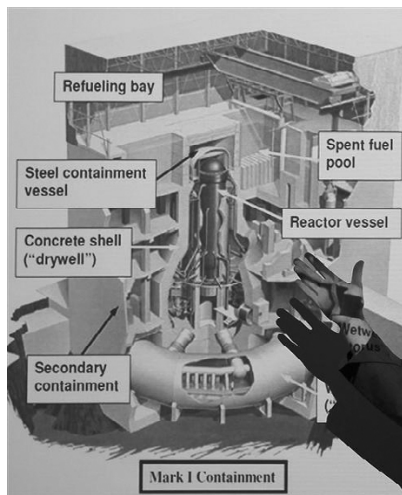


Figure 2. Boiling Water nuclear reactor containment vessel.

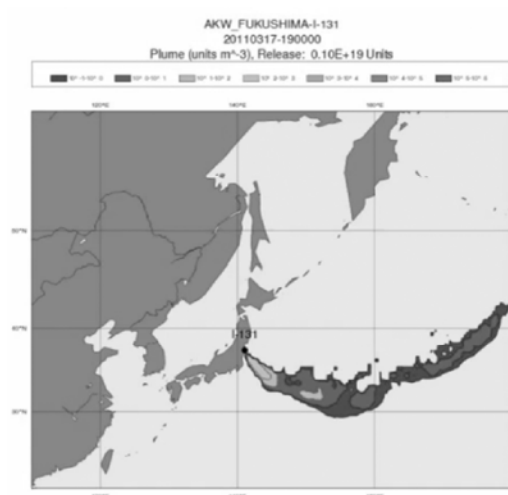


Figure 3. March 19th plume dispersal.

Nuclide	Activity
⁹⁵ Zr	14,000 Bq/m ²
⁹⁵ Nb	14,000 Bq/m ²
¹⁰³ Ru	7,800 Bq/m ²
¹³¹ I	890,000 Bq/m ²
¹³² Te, ¹³² I	260,000 Bq/m ²
¹³⁴ Cs	150,000 Bq/m ²
¹³⁶ Cs	44,000 Bq/m ²
¹³⁷ Cs	240,000 Bq/m ²
¹⁴⁰ Ba	180,000 Bq/m ²
¹⁴⁰ La	210,000 Bq/m ²
¹⁴¹ Ce	10,000 Bq/m ²

Figure 5. Hardy, E., et al. (1986). Observations and sampling by EML in Sweden, with preliminary gamma-ray spectrometric data. In: *Environmental Measurements Laboratory: A compendium of the Environmental Measurements Laboratory's research projects related to the Chernobyl nuclear accident: October 1, 1986*. Report No. EML-460. US Department of Energy. pg. 224-243. These are the Skutskar, Sweden (600 miles northwest of Chernobyl) ground deposition readings from May 5, 1986.

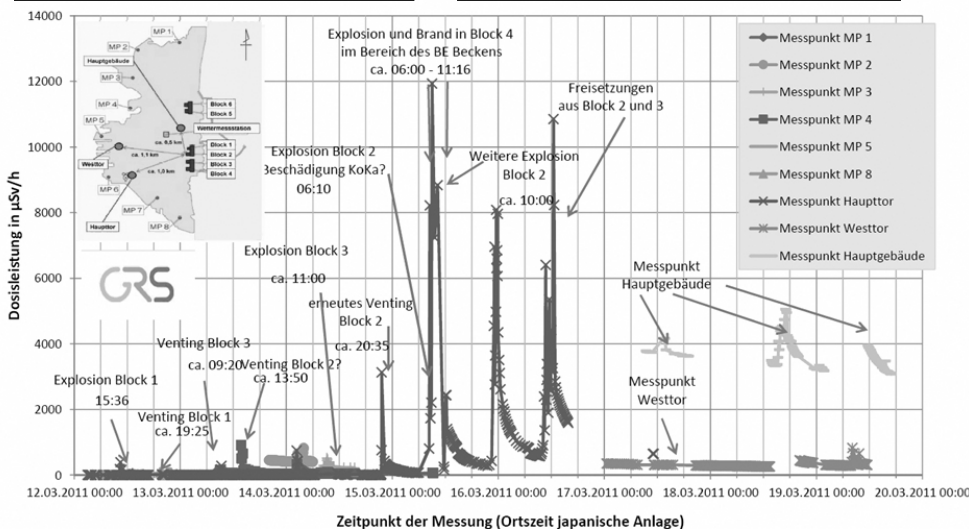


Figure 4. Fukushima Daiichi radiological releases.

Accident Plume Hot Zone

Notification of Elevated Risk to Area Communities and First Responders Living in the Vicinity of Boiling Water Nuclear Reactors

The attached elevated risk zone analysis has been compiled as a result of the ongoing series of nuclear accidents at the Fukushima Daiichi complex in Japan. This accident has graphically illustrated the elevated risk of living in the vicinity of aging boiling water nuclear reactors. In Japan, the heroic efforts of local and Tokyo fire companies and Tokyo Electric Power Company (TEPCO) workers have resulted in the partial control of seven ongoing loss-of-coolant accidents that could have otherwise evolved into a world disaster. A detailed description of the situation in Japan is contained in the Davistown Museum publication *Fukushima Daiichi: Nuclear Information Handbook: A Guide to Accident Terminology and Information Sources*, a clearly written guide to nuclear accidents for first responders, emergency management personnel, media, and concerned laypersons. It is an essential reference for evaluating the significance, impact, and emissions pathways of any nuclear accident. Currently available from Amazon.com in paperback (\$24), the *Handbook* will also be published in Kindle eBook format. An introduction to the text and its subject index guide can be found at www.davistownmuseum.org/publications.html#Handbook.

Two aging boiling water reactors in New England at Plymouth, MA, and Vernon, VT, are of particular interest to the editor and staff of the *Handbook* publisher, Pennywheel Press, all of whom live within either the accident hot plume zone or the ingestion plume zone. This particular attachment is directed at first responders and emergency management personnel who, in the event of a failure of backup diesel generators at either of these two reactors, would become the last line of defense for the prevention of a meltdown accident from evolving into a nuclear disaster.

There are important questions to ask about emergency preparedness in elevated risk zones. These include:

- **To what extent has your community fire department been involved in training exercises that would facilitate manual cooling of a melted reactor vessel and its adjacent spent fuel pool utilizing the fire equipment in your community?**
- Have the design flaws highlighted by the ongoing multiple interlocking meltdown event (MIME) in Japan and their potential for facilitating a nuclear accident been the subject of informed debate by first responders and emergency preparedness personnel in your community?

If the answers are no, you can obtain a copy of the *Nuclear Information Handbook* on Amazon.com.

Hundreds of thousands of people live within the 30-mile super hot plume zone around the Plymouth, MA, Pilgrim Power Generating Station reactor. Tens of thousands of residents live within the super hot plume zone of the Vermont Yankee facility. Media urgently needs to report on the necessity of additional emergency preparedness training by area first responders who will inevitably be involved with any future accident at these facilities. **A much broader debate is also needed about the unfortunate reality that hundreds of thousands of New Englanders living within hot plume zones may never be able to return to their communities as a result of a loss-of-coolant accident at either of these facilities.**

Area media, community leaders, concerned citizens, first responders, and/or emergency preparedness personnel need to join in a wider deliberation of the consequences of living in the vicinity of or downwind from aging boiling water nuclear reactors that give an ominous new meaning to the term “subprime” real estate.

Fukushima Daiichi
Nuclear Information
Handbook

A Guide to Accident Terminology and Information Sources

H. G. Brack

Davistown Museum

Department of Environmental History

Center for Biological Monitoring Archives

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First Edition

Front cover photo: This image made available from Tokyo Electric Power Co. via Kyodo News, shows the damaged No. 4 unit of the Fukushima Dai-ichi nuclear complex in Okumamachi, northeastern Japan, on Tuesday March 15, 2011. White smoke billows from the No. 3 unit. (AP Photo/Tokyo Electric Power Co. via Kyodo News)

Back cover photo: Fukushima Daiichi: Nuclear Facility Damage Overview. Image Collected March 16, 2011. Used with permission from DigitalGlobe Inc.

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Dedication

This *Handbook* is dedicated to the thousands of workers at the Fukushima Daiichi complex who have risked their lives improvising the manual cooling efforts that have kept the loss of coolant accidents from evolving into an even larger nuclear disaster.

Preface

This publication is sponsored by the Davistown Museum, a 501 (c) (3) organization. If not otherwise noted and with the exception of the Japan-disaster-related information, most of the contents of this *Handbook* have been extracted from the online archives of RADNET, the Center for Biological Monitoring's (CBM) nuclear information website. The CBM RADNET archives should not be confused with the EPA's online RadNet (<http://www.epa.gov/narel/radnet/>), which was organized after CBM's RADNET was incorporated within the Environmental History Department of the newly incorporated Davistown Museum (2000). The CBM RADNET archives republished in this *Handbook* include reporting units, definitions, radiological surveillance data, protection action guidelines, and commentary relevant to the ongoing accident at the Fukushima Daiichi nuclear complex. No citations from the RADNET archives date after 2000, though new definitions have been added to this *Handbook*. Comments, corrections, and additional information are solicited, curator@davistownmuseum.org.

Author Biography

A former volunteer fireman (1963-83), Skip Brack holds degrees in English from the University of Massachusetts (1966) and the University of Colorado (1967) and was an English instructor at the University of the Pacific. Skip was also a graduate student at the University of California, Berkeley, where he helped organize the Stop the Draft movement before leaving academia. In 1970, he was an Earth Day organizer, speaker, researcher, and Director of the New England Ecology Center. He organized the die-in at Logan Airport to protest the supersonic transport (SST), which was cancelled by the US Senate in December of 1970. After moving to West Jonesport, Maine, in the summer of 1970, he opened the Jonesport Wood Company, Inc. and has been in the used hand tool business ever since. Brack now operates tool stores in Hulls Cove, Searsport, and Liberty, Maine.

In 1972, Brack organized the Center for Biological Monitoring (1972-2000) and began collating research on chemical fallout and anthropogenic radiation. Skip moved to Hulls Cove in 1983, where he still lives. In 1994, Brack established RADNET: Nuclear Information on the Internet. In 1999, he founded the Davistown Museum, a regional tool, art, and history museum in Liberty, Maine. The Center for Biological Monitoring Archives is now a component of the museum's Department of Environmental History. The museum's extensive website is a major resource for persons, including homeschoolers, interested in New England's Native American, maritime, and industrial history, and the history of hand tools and how they were forged.

Author's publications

Environmental History

Radsan: Information Sampler on Long-lived Radionuclides

A Review of Radiological Surveillance Reports of Waste Effluents in Marine Pathways at the Maine Yankee Atomic Power Company at Wiscasset, Maine, 1970-1984: An Annotated Bibliography

Legacy for Our Children: The Unfunded Costs of Decommissioning the Maine Yankee Atomic Power Station

Anthropogenic Radioactivity: Chernobyl Fallout Data: 1986 - 2001

Patterns of Noncompliance: The Nuclear Regulatory Commission and the Maine Yankee Atomic Power Company: Generic and Site-specific Deficiencies in Radiological Surveillance Programs

Phenomenology of Biocatastrophe Publication Series
using the pseudonym Ephraim Tinkham

Volume 1: Essays on Biocatastrophe

Volume 2: Biocatastrophe Lexicon

Volume 3: Biocatastrophe: The Legacy of Human Ecology

New England Maritime and Industrial History

Norumbega Reconsidered: Mawooshen and the Wawenoc Diaspora

Davistown Museum *Hand Tools in History* Publication Series

Volume 6: Steel- and Toolmaking Strategies and Techniques before 1870

Volume 7: Art of the Edge Tool: The Ferrous Metallurgy of New England Shipsmiths and Toolmakers from the Construction of Maine's First Ship, the Pinnacle *Virginia* (1607), to 1882

Volume 8: The Classic Period of American Toolmaking, 1827-1930

Volume 9: An Archaeology of Tools: A Catalog of the Tool Collection of the Davistown Museum

Volume 10: Registry of Maine Toolmakers, 6th Edition

Volume 11: Handbook for Ironmongers: A Glossary of Ferrous Metallurgy Terms: A Voyage through the Labyrinth of Steel- and Toolmaking Strategies and Techniques 2000 BC to 1950

Phenomenology of Tools: Philosophical Observations on the Nature of Tool Wielding, revised second edition

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I. Fukushima Daiichi Disaster

Introduction

This *Handbook* results from over four decades of my research and commentary on anthropogenic radiation, the Maine Yankee Atomic Power Company, and the industrial history of a nation that perfected the manufacture of hand tools and atomic weapons but failed to design and build safe nuclear power reactors, including those it exported to other countries such as Japan. This edition of the *Nuclear Information Handbook* has been published as a result of the Fukushima Daiichi nuclear crisis that began on March 11, 2011 after a 9.0 earthquake off the coast of Japan. The tsunami that followed the earthquake destroyed the backup diesel generators at the Fukushima Daiichi complex. The loss of cooling capabilities that followed resulted in seven separate fuel assembly meltdown accidents, three in reactor vessels (loss of reactor coolant accident; LORCA) and four in their adjacent spent fuel pools (loss of coolant accident; LOCA). These seven accidents may be appropriately defined as a multiple interlocking meltdown event (MIME), a new acronym suitable for describing what is a unique occurrence in nuclear industrial history. Excluding all six other Fukushima Daiichi accident sites, the radiation release from the fires and hydrogen explosion in the spent fuel pool in Reactor 4 may be larger than the source term from the Chernobyl accident.

This *Handbook* begins with a synopsis of the Fukushima Daiichi accident cycle and continues with a description of relevant dosage reporting units, definitions, and concepts pertaining to nuclear accidents. It also includes information about baseline data, plume source points, pathways, and radiation protection guidelines. Much of the general public's fear of "radiation" is based on ignorance of its sources, constituents, and potential health physics impact. This *Handbook* hopes to clarify the confusing reporting units of radiation exposure and measurement and provide guidance for non-experts to evaluate the significance of the Fukushima Daiichi or any other nuclear accident.

This *Handbook* provides:

- An overview and time line of the accident at the Fukushima Daiichi reactor facilities, including a description of the fuel assemblies currently in meltdown status.
- A concise introduction to radiation reporting units, exposure and protection action guidelines, pathways, biologically significant radioisotopes, and contamination levels of concern about point sources of anthropogenic radioactivity in the context of background levels of naturally occurring radiation.
- Access to the most important Internet accident information resources, including those of the Japanese government (NISA and MEXT), International Atomic

Energy Agency (IAEA), US EPA, US NRC, IRSN (France), and University of California, Berkeley.

- A comprehensive overview of the radiological impact of the Chernobyl accident. Extracted from the online archives of RADNET, the Chernobyl bibliography and the data it contains provide a useful guideline for evaluating the radiological impact of the accident in Japan.
- Historic contamination baseline data pertaining to weapons testing fallout, nuclear power production, and the many nuclear waste plume sources that characterize the atomic age.
- An exploration of the decommissioning of the Maine Yankee Atomic Power Co. at Wiscasset, ME as a paradigm of the problems encountered at many operating nuclear reactors, including the fuel cladding failure accidents at Maine Yankee, which led to its closing.

Caveat

The *Nuclear Information Handbook* and the RADNET archives provide no specific information on the health physics impact of any nuclear accident or source point of anthropogenic radioactivity. In this *Handbook*, and in the RADNET archives, the term “radiological impact” refers to accident deposition levels of long-lived isotopes, especially the indicator isotope Cs-137, and their concentration levels in pathways to human exposure and consumption. No evaluation of the health physics impact of radiation exposure can be made without this data. The FDA-derived intervention levels, the MEXT radiation and daily life graphic, the Wikipedia sievert exposure guidelines, and RADNET’s terrestrial contamination levels of concern and the dose assessment criteria in the radiation protection guidelines reprinted in this *Handbook* provide essential information allowing the non-expert to evaluate the significance of data being reported in Japan, the United States, and elsewhere.

Human exposure to ambient radiation is expressed in sieverts and grays, reporting units essential for estimating the severity of an accident and its immediate impact on humans. Accurate accident dose assessment is contingent upon the measurement of the indicator isotopes radiocesium (Cs-137) and radioiodine (I-131), followed by the documentation of their uptake in the food webs that result in exposure to humans, as expressed in the reporting units described below. An evaluation of the health physics impact of any nuclear accident, including the Fukushima Daiichi disaster, cannot be completed without a comprehensive analysis of the source term (radiation release inventory), deposition concentrations, and pathways of the isotopes discharged during this or any other accident. The information contained in this *Handbook* is intended to help the

layperson navigate the labyrinths of the world of nuclear information and its many equivocations and rituals of evasion. It is hoped that readers of this *Handbook* will be able to go beyond the confusing and often misleading jargon of ambient exposure as measured in microsieverts and nanograys and find the answers to fundamental questions about contamination deposition and concentration levels expressed in becquerels per square meter, becquerels per kilogram, and becquerels per liter.

Fukushima Daiichi Accident Status

It is now evident that seven nuclear accidents have occurred at the Fukushima Daiichi complex with the potential to surpass the source term (release totals) of the Chernobyl accident. On Tuesday, April 12, 2011 the Japanese government confirmed this possibility by raising the rating of the severity of the accident to a level 7 on the INES nuclear event scale (see below), estimating that radiation releases had already reached 10% of Chernobyl levels and possibly higher. Commenting on the possible future chronic releases of radiation from this accident, TEPCO executive Junichi Mutsumoto notes, “the radiation leak has not stopped completely, and our concern is that it could eventually exceed Chernobyl.” (*The New York Times* April 13, 2011, A-5). In fact, the source term of this complex accident-in-progress has already surpassed the Chernobyl releases.

All seven nuclear accidents in progress at the Fukushima Daiichi reactor complex involved fuel assembly melting events followed by hydrogen explosion blowouts, fires associated with burning zirconium fuel rod claddings, and the continuation of nuclear fuel criticality (fission chain reactions). The first indications of major problems at the reactor complex were the rapid drop in water levels in reactor vessels 1 - 3 and in the spent fuel pools of Reactors 1 - 4. This was followed by fires, which both preceded and followed three hydrogen gas explosions that resulted from the continued generation of heat in the reactor vessels of Units 1 - 3. These explosions, graphically depicted by electronic and print media, discharged large quantities of volatile fission products (Cs-137 and I-131) into the atmosphere where they were dispersed in the immediate vicinity of the reactor complex, eastward over the Pacific Ocean, and to many inland locations.

The hydrogen explosion in the spent fuel pool of Reactor 4 on March 15th, 2011 released a substantial percentage of the content of its 1,479 fuel assemblies, each of which contained at least 10,000 curies of Cs-137. Another 2,889 fuel assemblies were involved in meltdown events in Reactors 1 - 3 and their spent fuel pools. Damage to the primary containment structures at Reactors 1 and 2 and melted fuel in their dry wells may prevent construction of a closed loop cooling system, which the Tokyo Electric Power Company (TEPCO) indicated is the key step in restoring “normal cooling” to the damaged units at Fukushima Daiichi. Only after closed loop cooling systems are constructed at all seven accident locations will the ongoing, though dramatically reduced, fission process in melted fuel assemblies evolve to a “cold shutdown” status.

The accident at the complex will be a long-term chronic point source of radiological contamination as long as some degree of fissile activity is still occurring. Radiation releases, including those via secondary and tertiary pathways, may continue for years and will likely far exceed those from the Chernobyl accident.

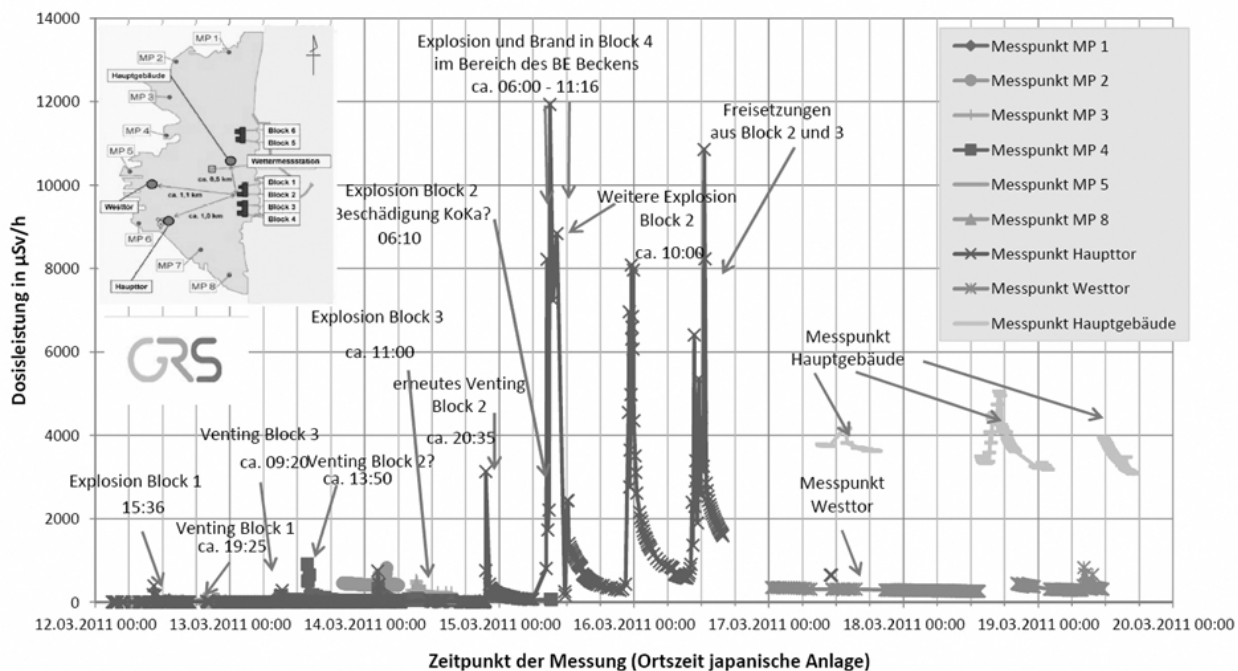


Figure 1. Fukushima Daiichi radiological releases
[\(http://energyfromthorium.com/2011/03/30/areva-fd-presentation/\)](http://energyfromthorium.com/2011/03/30/areva-fd-presentation/).

At the accident site itself, “peak discharges from the Fukushima Daiichi facility appear to have occurred between March 14th and 16th according to a new assessment... based largely on computer models showing very heavy emissions of radioactive iodine and cesium.” (*The New York Times* April 15, 2011). *Figure 1* graphically depicts these emissions though the reporting unit, thousands of microsieverts per hour, tells us nothing about the isotopic concentration levels of these releases. An important component of these peak emission releases occurred when a fire broke out at the spent fuel pool in Reactor 4, which was not operating at the time of the tsunami. A fourth hydrogen explosion was apparently associated with this fire and totally destroyed the outer containment of the spent fuel pool at Reactor 4. The contents of this spent fuel pool had just been removed from this reactor. Peak accident radiation emissions of fission products, including a substantial percentage of the spent fuel pool inventory of Reactor 4, occurred during this fire, which was “successfully contained within a few hours” (TEPCO 2011) only to start up again the next day.

The continuing challenge of cooling seven meltdown events creates the possibility of a future release of large amounts of radioactivity if fuel assembly melting results in the future resumption of high levels of criticality. The evolution of a worst case scenario appears to have been mitigated by ongoing manual cooling efforts. Initially these cooling efforts involved helicopters and fire equipment, an extremely primitive way to control seven ongoing meltdown events. A system of electrically-powered pumps has now been improvised to pump water into the reactor vessels and spent fuel pools, all of which contain damaged fuel assemblies that have suffered loss of cooling. The intense effort by TEPCO to cool the fuel assemblies may be successful in preventing a significant increase in the fission chain reactions essential to the resumption of explosive criticality in the reactor vessels and the fuel assemblies in the spent fuel pools. In the hoped for scenario of continued cooling, there may not be a significant increase in airborne contamination beyond what has already occurred. The continued manual cooling of the reactor vessels and spent fuel pools, whose emissions-containing closed loop cooling systems were destroyed by the hydrogen explosion blowouts, is resulting in large discharges of highly radioactive water into marine pathways. This unexpected washout pathway did not characterize the Chernobyl accident; the last nuclear accident involving discharges to the marine environment occurred at Sellafield in England. The creation, storage, and dispersal/disposal of radioactive water as a result of ongoing cooling efforts may release greater quantities of radiation than the series of hydrogen explosions, which characterized the first stage of the accident. At Fukushima Daiichi, the best case scenario involves the successful construction of seven closed loop cooling systems to capture the emissions from the exposed and melted fuel assemblies, which still exhibit low levels of criticality. The harsh reality of damaged facilities in a highly radioactive environment suggests instead that the struggle to cool the zirconium-clad fuel assemblies in the reactor vessels and spent fuel pools “may continue indefinitely - possibly for three to five years.” (*The New York Times* March 30, 2011). The ultimate solution to the problem of disposing of the highly radioactive legacy of this accident will probably be the construction of an entirely new accident waste storage facility.

The accident time line printed in this text provides a snapshot of the sequence of the events during the first five weeks following the accident. Chronic liquid- and steam-associated emissions will continue until the temperature of the melted and/or damaged fuel assemblies are stabilized and are returned to a cold shutdown status. The critical unanswered questions are: how long will accident emissions continue; will their intensity gradually abate; what are their secondary and tertiary pathways and concentration levels; and what is the total accident source term (release inventory)?

Radiological Surveillance Information Availability

Accident Site Reactor Design

US Nuclear Regulatory Commission Accident Update (NYT 4/6/11)

Accident Source Term Sketch

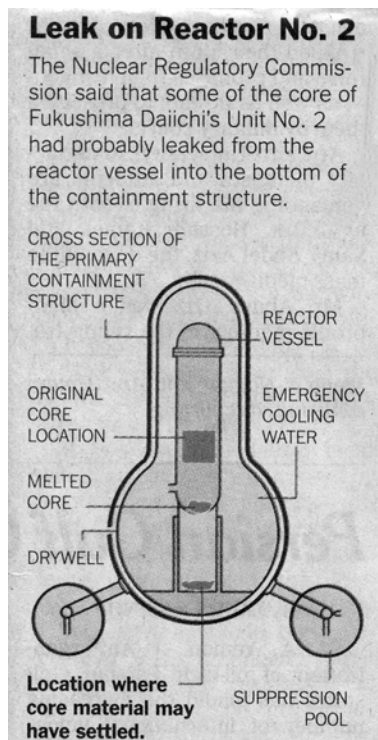


Figure 2. Reactor 2 vessel design. (Glanz April 5, 2011).

The nuclear accidents at the Fukushima Daiichi complex, an ongoing MIME, can be divided into two phases. Phase 1 involved a loss of water coolant in all seven environments. The exposed fuel assemblies began melting; this was followed by the sequence of hydrogen gas explosions, which occurred during the first five days of the accident at Reactors 1 - 3 and the spent fuel pool of Reactor 4. These were followed by five more days of steam and smoke emissions, much of which originated from Reactors 2 and 3. Peak radiation releases occurred during these first ten days. The estimated (modeled) source term of radiocesium during this period are listed below as Phase 1 releases. The large size of these releases is suggested by the terminology “tens of thousands of terabecquerels per hour” (NISA 2011) were released during the early stages of the accident. One terabecquerel = 27 Ci (curies); if 37,000 terabecquerels per hour were released in a series of pulses, which lasted 72 hours, the hourly release rate would be 1 million curies with a total release of 72 million curies. These initial releases contained large quantities of very short-lived radioisotopes,

such as I-133 and noble gasses, making it difficult to estimate the release of Cs-137, Cs-134, and other long-lived radioisotopes. While the surveys of ground deposition that followed the Chernobyl accident made it relatively easy to estimate the Cs-137 and Cs-134 source terms, the dispersion of most radiocesium over the Pacific Ocean in the Fukushima Daiichi accident makes calculation of its source term much more difficult. Because the Fukushima Daiichi inventories (7) of Cs-137 are much larger than Chernobyl (± 8 million Ci / 10,000 Ci per fuel assembly = 800 fuel assembly equivalents), a sketch of the Japan accident Cs-137 source term can be made by an evaluation of the condition of the fuel assemblies, all of which have suffered significant damage, melting, and, in the case of the spent fuel pool assemblies, actual dispersion.

Phase 1 Estimated Release

A breakdown of the seven accident source terms can be reasonably estimated utilizing Cs-137 as the indicator isotope. Each fuel assembly contains a minimum of 10,000 Ci of Cs-137. Our modeling of Cs-137 releases at Fukushima Daiichi can then be compared with the Chernobyl release of 2.7 million Ci of Cs-137. In modeling the estimated releases from both the reactor vessels and the spent fuel pool assemblies, it is important to note the severe damage to each group of fuel assemblies once they were uncovered by the loss of cooling water and they began melting. According to the Kyodo News Agency, 70% of the fuel rods in Reactor 1 were damaged. In Reactor 2, the fuel rods were fully exposed for a period of time on Monday, March 14, 2011; 33% of the fuel rods are reported as being damaged. The NRC sketch in *Figure 3* suggests that this might be a conservative estimate as some fuel assemblies have melted into the dry well. The condition of the fuel rods in Reactor 3 is unknown, but they are probably significantly damaged. All the fuel rods in the Reactor 4 spent fuel pool were damaged by the sequence of fires and the hydrogen explosion that dispersed significant portions of the fuel rod fission products onto the plant site as well as out into the ocean on March 15, 2011. Smoke and steam emissions from fuel melting continued for ten days after the peak emissions of March 12 – 15. The fuel assemblies in the spent fuel pools of Reactors 1 - 3 have also experienced significant melting and suffered extensive damage in the hydrogen explosions that destroyed the secondary containment structures in each facility.

Table 1. Fuel assembly synopsis.

Reactor vessel	Reactor assemblies	Spent fuel pool assemblies
1	400	292
2	548	587
3	548	514
4	Empty	(1479)
Total	1496	1393 (+1479)

1. If 5% of the Cs-137 in the reactor fuel assemblies was released out of a total inventory of 14,960,000 Ci of Cs-137, then 748,000 Ci of Cs-137 is the estimated release from these three point sources. This does not include the shorter-lived Cs-134 ($1/2 T = 2.1$ years).
2. If 10% of the Cs-137 in the spent fuel pools of Units 1 - 3 was released, then 1,393,000 Ci of Cs-137 is the estimated release from these three point sources.
3. If 20% of the Cs-137 in the highly damaged spent fuel pool of Reactor 4 was released, then 2,958,000 Ci of Cs-137 is the estimated release from this source point.

Our modeling of the source term of Cs-137 during the first ten days of these accidents is, therefore, 5,099,000 Ci of Cs-137, compared with the release of 2,700,000 Ci of Cs-137 at the Chernobyl accident. Due to the extreme damage suffered by all seven Fukushima Daiichi Units and the melting and dispersal of reactor and spent fuel, it is highly unlikely that the Fukushima Daiichi source term for Cs-137 is only one tenth that of Chernobyl. Its accurate measurement by ground deposition analyses is problematic as much of the Cs-137 source term was dispersed over the Pacific Ocean.

Phase 2 Estimated Release

The second phase of the accident at the Fukushima Daiichi complex involves the chronic release of low levels of radioactivity. If 37 terabecquerels per hour of radioactivity (not 37,000 terabecquerels) are released for one year, the release rate is 1,000 Ci/hr or 24,000 Ci/day for a total of 8,660,000 Ci of radioactivity. The primary mode of release in phase 2 of this MIME is, and will continue to be, the remobilization and transport of fuel-pellet-derived fission products by ongoing cooling efforts, i.e. the washout pathway. Only if high levels of fissile activity – nuclear chain reactions – reoccur, will airborne emissions exceed those from the washout pathway. If 5% of the total source term of both washout pathway and aerial emissions is Cs-137 (since criticality has subsided but not ended, less short-lived radioisotopes are being released), then chronic releases from all seven fuel assembly melting events would add another 433,000 Ci to the total Cs-137 source term, which would be 5,532,000 Ci. These modeled estimates of the releases from the ongoing accidents in Japan are actually very conservative. There is the possibility that much more than 5% of the reactor vessels now melted fuel assembly fission products have already been released. The same observation could be made about the modeled releases from the spent fuel pools, especially those at the highly damaged Reactor 4 spent fuel pool. The Cs-137 source term at Chernobyl was about 30% of the total of the long-lived isotopic source term. The shorter-lived isotopes, including the radioiodine group, initially dominated the release plumes; after 60 days Cs-137 ($1/2T = 30.174$ years) and Cs-134 emerged as the most important source term isotopes from a health physics perspective.

Accident Event Sequence

Fukushima Daiichi Radiological Surveillance Data Sources

Fukushima Daiichi Accident Time Line

Site and Media Specific Radiological Data

Fukushima Daiichi Subprime Boiling Water Reactor Design

Conundrum: Reactor Vessel Integrity

Cooling Event Releases

Fukushima Daiichi: A Black Swan Event

Disaster Timeframe

Fukushima Daiichi vs. Three Mile Island Cleanup

The Legacy of Plutonium

A Closed Loop Cooling System

Nuclear Mis-information?

Information Availability

Bulldozing

Water In/Water Out: Leak Rates

The key to deciphering the environmental impact of the seven interrelated fuel assembly melting events at Fukushima Daiichi involves the destinations of the water used to cool down the reactor fuel. Reactor vessels and spent fuel pools do not usually leak water during normal operations nor emit radioactive steam into the atmosphere. The current effort to avoid a full scale meltdown involves the constant pumping of water into three reactors and four spent fuel pools. *The New York Times* noted, “as the water boils in the reactors, pressure rises too high to pump in more water, so workers have to vent to the atmosphere” (April 18, 2011) to relieve the pressure before feeding in more water. “At some reactors the arms of the trucks that deliver the water have been placed over the damaged walls of the buildings, enabling water to be shot more directly **at** the reactors and pools and reducing runoff.” TEPCO announced a plan to build an entirely new closed loop cooling system, a myopic goal that would take months to halt the release of radioactive steam and water (Belson 2011, A1). Radioactive emissions at the accident

site have two pathways associated with cooling efforts: radioactive water washout, now the intense object of recovery, and radioactive steam, which is more difficult to recover. More data leaks about water leaks is needed – where is WikiLeaks when we need it?

Evaluation of the total Fukushima Daiichi source term (release inventory) at all seven facilities now experiencing fuel assembly melting events is contingent upon documenting the rate at which cooling water “leaks into the environment” either as radioactive water or radioactive steam. Since all four reactor buildings have been severely damaged by hydrogen explosions (blowouts), restoration of “normal” cooling rates is highly unlikely. Accurate measurement of the variations in radioactive water or steam releases will be essential to determine the ongoing source term releases of this accident. Ultimately, the question will arise as to what percentage of the radioisotope inventory was released from each unit and what percentage of the original core and fuel pool inventories remained onsite? Obviously, the resumption of criticality at one or more units will create a plume of highly radioactive gaseous emissions, of which radioactive steam will only be one component. If such emissions occurred early in the accident due to ongoing criticality, a possible cause of the hydrogen explosions that were graphically illustrated on TV, neither the Japanese government, TEPCO, the IAEA, nor the US NRC have mentioned criticality-derived emissions as a component of these ongoing accidents.

Fukushima Daiichi Lingering Questions

There are a number of unanswered questions that need to be addressed as the accident at Fukushima Daiichi evolves from a potentially world-threatening catastrophic disaster to the nuclear power industry’s largest quagmire of multiple point sources of chronic radiation emissions.

1. Did the reactor vessel and spent fuel pool cooling failures that occurred at the beginning of the accident result in the resumption of criticality at any of the units or was there lingering low-level criticality in the reactor vessels at the time the tsunami struck and cooling capabilities were lost?
2. Since radiation emissions have diminished since the four hydrogen gas explosions occurred, are there any remaining fuel assemblies that are still critical, i.e. that are undergoing fission chain reactions such as in the damaged reactor vessel of Units 1 and 2, which have melted fuel in the lower sections of their reactor vessel and in their underlying dry wells? (See *Figure 3*.)
3. Will TEPCO be able to prevent any future rise in temperature within the melted fuel assemblies as appeared to be happening in Reactor 2 as recently as April 17, 2011?

4. Will continued manual cooling efforts succeed in the further reduction of heat generation in the fuel assemblies that melted as a result of loss of reactor vessel and spent fuel coolant?
5. Will the ultimate goal of a “cold shutdown” where no more boiling occurs be successfully implemented at all seven accident locations and when will this occur?
6. To what extent will damage to the secondary reactor containment buildings and the reactor and water cooling systems prevent construction of improved closed loop cooling systems?
7. Will a return to cold shutdown status have to await construction of a specially designed onsite melted fuel storage facility and how long will this construction project take?
8. How long will manual cooling efforts generate radioactive steam emissions, given the fact that the roofing over all four spent fuel pools has been destroyed?
9. How long will manual cooling efforts result in the washout of fuel assembly-derived fission products to the terrestrial and especially the marine environments adjacent to the reactor complex?
10. To what extent will TEPCO be successful in the recovery of radioactive water and where will it be stored?
11. Will the radioactive water component of the accident source term exceed that of atmospheric gaseous and particulate emissions?
12. Will the Japanese government, TEPCO, and the International Atomic Energy Agency be able to reconstruct the source term from **each** of the environments experiencing loss of coolant accidents, and for each source term pathway, especially including the washout pathway. How many years will this analysis take?

The answers to these questions will help all concerned spectators of the unfolding tragedy in Japan, including the citizens of Japan who are so severely impacted by the radiological contamination of their homeland, better understand what has taken place. The accidents at Fukushima Daiichi involve fuel cladding failures on a grand scale. The source term from the hydrogen explosion in the spent fuel pool of Reactor 4, which may have released $\pm 25\%$ of its inventory, may itself exceed the total source term of the Chernobyl accident. Any third grade honor student can do the math and make a rough estimate, for example, of the source term of cesium-137. It is public knowledge, courtesy of *The New York Times*, that the spent fuel pool at Reactor 4 contained 1,479 fuel assemblies. It is also well-known that a fuel assembly in every nuclear reactor has accumulated at least 10,000 curies of Cs-137. Ten thousand multiplied by 1,479 equals 14,790,000 curies as the minimum content of Cs-137 in this recently-loaded spent fuel

pool. The Chernobyl source term for Cs-137 was 2.7 million curies. If 25% of the content of the spent fuel pool of Reactor 4 was ejected from the confines of the destroyed building by a hydrogen explosion and associated fires, deposited locally as fuel assembly fragments, windblown steam and smoke emissions, or washed out fission products by manual cooling efforts, the source term release from **only** the Reactor 4 spent fuel pool was _____ curies of Cs-137. Okay kids, do the math and fill in the answer, and then mail the answer to your local newspaper or electronic media outlet. Who will be the first to mention that the source term release from just one of the seven accident locations in Japan is probably greater than that from Chernobyl, even though it was not as widely deposited in terrestrial environments as the tropospheric dispersion of emissions from the Chernobyl explosion? Fox News, CNN, PBS, NYT, WSJ, Charlie Rose, Amy Goodman, etc.: Can you rise to the occasion, or do you think this information should be kept secret? (Answer: $\pm 3,697,500$ Ci of Cs-137 may have been released just from the explosion that destroyed spent fuel pool 4.) This accident will continue indefinitely because there are six other radioactive contamination point sources in this multiple interlocking meltdown event (MIME). It is highly unlikely that the current estimate by TEPCO and the Japanese government that the accident release is only 10% of that at Chernobyl is accurate.

As this book was going to press, all media seem obsessed with the Royal Wedding, tornados in the American midlands, the death of Osama bin Laden, and a Mississippi River flood disaster that will transport more ecotoxins into the Gulf of Mexico than those discharged by the Gulf oil spill. As a result of the combination of too much news to report and ongoing psychic numbness, will the spectacle of the ongoing agony of the citizens of Japan no longer be deemed newsworthy?

II. Basic Definitions and Concepts

The following guidelines and reporting units have been extracted from the Center for Biological Monitoring RADNET archives and contemporary online information sources such as the United States Food and Drug Administration (US FDA), United States Department of Energy (US DOE), United States Environmental Protection Agency (US EPA), Centers for Disease Control (CDC), the International Atomic Energy Agency (IAEA), Institute for Energy and Environmental Research (IEER), Greenpeace, and Wikipedia.org. Additional definitions and explanations continue in *Section III*.

Additional Definitions and Concepts. The following delineation of reporting units is prefaced by comments on the problem of evaluating dose assessments from exposure to ambient radiation in the context of multiple pathways of radiation exposure, including ingestion, inhalation, and secondary/tertiary pathway exposures.

The Problem of Exposure to Ambient Radiation

The fly in the ointment pertaining to any nuclear accident or nuclear discharge exposure scenario is that the radiation-detecting equipment that measures ambient air contamination or the surface contamination of radioactivity on skin and clothing (in reporting units of absorbed dose, e.g. microsieverts/hour, or in rate of space dose, e.g. nanograys per hour) provides only a fragment of the information needed to evaluate actual exposure. Accidents such as the ongoing disaster in Japan create plumes of radiation, which are then deposited on terrestrial landscapes and in marine environments by rainfall events as well as by dry deposition. The accidents at the Fukushima Daiichi facility are also characterized by the discharge of large volumes of contaminated seawater as a result of the improvised attempts to cool the fuel assemblies.

Contamination derived from these and other accidental releases is then taken up by the biogeochemical cycles of the earth's biosphere, exposing all living creatures, including humans, to anthropogenic (manmade) radiation. The accidents at the Fukushima Daiichi facility may well turn out to be historically difficult-to-remediate long-term chronic contamination point sources, with multiple exposure pathways ranging from ground shine and re-suspended and remobilized deposition to contamination of terrestrial and marine food webs. Anomalous pathways exposure may include wash-up of contaminated tsunami debris on the shores of North America.

Once an accident plume has passed, measurements of ambient radioactivity exposure levels provide little or no information about total accident exposure for communities living within principle fallout zones, or for population groups whose principle exposure is through contaminated food products. The tragedy of the ongoing Japan disaster is that radioactivity will be emitted continuously for a long period of time; its terrestrial

deposition will depend on accident duration and intensity, wind direction, ocean current dispersal of liquid contaminants, and the re-concentration of radioisotopes after their deposition in marine sediments. Rhetorical commentary on the accident plume, such as “Radioactivity is low,” or “Such and such location will have a minimum impact from this accident” should have zero credibility. The actual evaluation of human exposure to accident-derived radioactivity from Fukushima Daiichi must await detailed isotope and media-specific analysis of the contaminant load in all impacted abiotic and biotic environments. In places such as California, Oregon, and Washington, which began receiving tiny amounts of radioactivity on Saturday, March 19, 2011, an evaluation of the significance of the radiological impact of the Fukushima Daiichi accidents can only be measured by analysis of the soil deposition of indicator isotopes, such as I-131 ($1/2 T = 8$ days) and Cs-137 ($1/2 T = 30$ years), **as measured in becquerels per square meter or per liter or per kilogram of abiotic and biotic media**. Low or non-existent concentrations of radioactivity in air, as measured in microbecquerels per cubic meter ($\mu\text{Bq}/\text{m}^3$) or microsieverts per hour ($\mu\text{Sv}/\text{hr}$) provide no information about plume passage and the deposition that has already occurred. If new cesium deposits can be documented (on top of old weapons testing and Chernobyl radiocesium baseline deposits), new deposits of other biologically significant isotopes, including MOX fuel-derived plutonium-239 ($1/2 T = \pm 24,000$ years), will also be present. Due to its short radiological half-life, I-131 is always an indicator of the recent discharge of newly created fission products. No I-131 contamination was detectable a few months after the Chernobyl accident ended, due to its short half-life. Nonetheless, hundreds of millions of citizens in Russia and Europe were exposed to biologically significant concentrations of thyroid-seeking I-131 before it decayed. The analytic techniques that measure gamma radiation, and beta/gamma-emitting radiocesium and radioiodine isotopes, cannot be used to measure contamination of biotic and abiotic media by long-lived alpha-emitting plutonium, curium, and americium, which will require time-consuming laboratory analysis to evaluate.

Exposure to accident plumes cannot be evaluated until the following information is available:

- How many becquerels per square meter of the accident indicator isotope cesium-137 have been deposited in my community?
- How many becquerels per kilogram of cesium-137 are in the food that my family and community are ingesting?
- How many becquerels per liter of cesium-137 are in the milk, including breast milk, that my children are drinking?

- How many becquerels of iodine-131 are in the public and private drinking water supplies that my family is drinking?
- How many becquerels of iodine-131 are in the milk, including breast milk, that my children are drinking?
- How many becquerels of iodine-131 are in the leafy vegetables, mushrooms, and other foods that my family is eating?

The presence of these indicator isotopes in amounts approaching protection action guidelines or levels of concern also mean that individuals, families, and communities are being exposed to the wide variety of other isotopes released by nuclear accidents. The radiological fallout data compiled after the Chernobyl accident, much of it summarized in *Section VIII. Chernobyl Fallout Data*, provide a glimpse into the many isotopes contained in any accident source term release. The Chernobyl ground deposition monitored in Skutskar, Sweden (see Sweden: Hardy 1986) included important nuclides of concern associated with all accidents: Zr-95, Nb-95, Ru-103, Te-132, Cs-134, Ba-140, La-140, and Ce-141. At this location, background radiation rose to 900 $\mu\text{R/hr}$ (9 $\mu\text{Sv/hr}$) in comparison to Stockholm where it remained near background levels at 30 $\mu\text{R/hr}$ (0.3 $\mu\text{Sv/hr}$). Another Swedish researcher notes background radiation as 10 to 15 $\mu\text{R/hr}$ (0.1 to 0.15 $\mu\text{Sv/hr}$) (Sweden: Reizenstein 1987). Given the high levels of ground deposition at Skutskar, the elevated ambient or background radiation level graphically illustrates how little information about the seriousness of a nuclear accident can be derived from background readings that often vary widely under normal conditions and may not appear excessively high even after a major fallout event, the duration of which may only last a few hours.

The following definitions are intended as a guide to the basic terminology essential to understanding the environmental impact and health physics implications of the unfolding disaster at the Fukushima Daiichi facility or any other nuclear accident. The fundamental question that all concerned world citizens may have, or may soon have, is: how much radioactivity is my community and my family being exposed to?

Reporting Units for Radiation Exposure and Environmental Contamination

Electromagnetic Radiation (EMR)

Background Radiation

Exposure Guidelines

Classification of Radioactive Waste

Checklist of Biologically Significant Radionuclides

Basic Radiotoxicity for Ingestion of some Radionuclides

Selected Radiation Level Guidelines

Banana Equivalent Dose (BED)

Exposure Pathways

The Risks of Exposure to a Passing Plume

MOX Fuel Pathway Alert

Fukushima Daiichi Washout Pathway

Sediment as a Repository of Discharges to the Marine Environment

Deposition Mechanisms

MEXT Sketch of Radiation Exposure

EPA Radiation Exposure Action Level

Terrestrial Contamination Levels of Concern for the Indicator Isotope Cs-137

Sudden increases in the environmental presence of the indicator isotope Cs-137 are indicative of new or reactivated point sources of anthropogenic radioactivity, e.g. nuclear weapons test explosions or nuclear accidents. The fissile activity that results in the production of Cs-137 also produces the short-lived isotope Iodine-131 ($t_{1/2} = 8$

days), among the most biologically significant of all anthropogenic radioactive isotopes. Increasing deposition of Cs-137 automatically mandates intensive monitoring for the presence of I-131 in pathways to human consumption.

- **3.7 Bq/m²**: Begin monitoring of ambient exposure radiation levels (microsieverts per hour), terrestrial contamination levels above background (Cs-137, Bq/m²), and contamination in rainwater (I-131, Bq/l) via the Weather Channel and the EPA, CDC, DOE, FDA, IAEA, state, and local websites, as well as other online information sources.
- **37 Bq/m²**: Expand monitoring to include measurements of local contamination of food, water, and milk by indicator nuclides I-131 and Cs-137 as measured in Bq/kg or Bq/l. Begin protective actions: avoid exposure to rainfall events, remove shoes and clothing before entering domestic environments, and shower after exposure to rain.
- **370 Bq/m²**: Expand protective actions: stay indoors whenever possible, close windows, seal openings, cover gardens with tarps, shelter livestock, avoid ingestion of leafy vegetables and fruits harvested in fallout areas. Expand monitoring of food, water, and milk; discard or avoid ingesting foods and water contaminated by the indicator nuclides I-131 and Cs-137 above 370 Bq/kg or Bq/l (10,000 picocuries, the protection action level used by the US FDA to dispose of imported foods contaminated by Chernobyl-derived fallout). Continue monitoring of ambient radiation levels.
- **3,700 Bq/m²**: Expand protective actions to restrict movement of children, outside workers, nonessential travel, and recreational activities such as hiking and sunbathing. Closely monitor food, milk, and water intake, sources, and radiation levels. Begin using respirators in soil cultivation work. Begin maximum use of information technology to keep informed of ongoing emissions.
- **37,000 Bq/m²**: Prepare to evacuate to a safer zone, e.g. the southern hemisphere or another planet.

Without the systematic compilation of the distribution patterns of the indicator radioisotopes Iodine-131 ($1/2T = 8$ days) and Cs-137 ($1/2T = 30$ years), no reasonable evaluation of the health physics impact of the Fukushima Daiichi disaster or any other nuclear accident or point source can be tabulated.

Plume Hot Zones

Numerous short-lived nuclides characterize any quick release accident. Plume hot zones can be divided into the following three major categories:

- Super hot zone (± 2 hours): initial ambient radiation levels following any accident will be highly elevated due to the presence of short-lived isotopes such as Xe-137 ($1/2 T = 3.81$ m; daughter product is Cs-137), I-132 ($1/2 T = 2.3$ h), I-133 ($1/2 T$

= 2.8 h), Te-129 ($1/2 T = 69.6$ m), and Te-131 ($1/2 T = 25$ m). These isotopes are often associated with hot particles. The health physics impact of these short-lived isotopes is entirely contingent upon weather conditions. A worst case scenario involves calm weather conditions accompanied by rainfall. In the event of a hydrogen gas explosion, as occurred in Japan, high levels of radiation would remain at ground level; survival would be dependent upon the availability of self-contained breathing apparatus in combination with some sort of fallout shelter such as an interior bedroom or cellar. Close-in super hot zone fallout would also be associated with drizzle and fog. The US NRC guideline of a ten mile evacuation zone would be relevant in the context of calm weather where the plume super hot zone was distributed more or less evenly around the accident site. Both the Chernobyl accident and the Fukushima Daiichi hydrogen explosions involved wind speeds of 10 to 15 miles per hour, which helpfully dispersed the plume hot zone above ground level. In the case of the accident in Japan, much of the plume super hot zone was carried over the Pacific Ocean by prevailing winds. In an accident scenario at a US boiling water reactor, such as the Pilgrim Nuclear Generating Station in Plymouth, MA, the super hot plume zone could conceivably extend downwind from the reactor site 10 to 25 miles, extending to communities such as Kingston, Marshfield, Scituate, Cohasset, Hingham, Rockland, and Pembroke when prevailing winds are from the south.

- Hot zone (2 days): An accident-derived plume hot zone is associated with the dispersal and deposition of Xe-135 ($1/2 T = 9.14$ h), Ce-143 ($1/2 T = 33$ h), Mo-99 ($1/2 T = 67$ h), Np-239 ($1/2 T = 2.35$ d; daughter product is Pu-239), Te-132 ($1/2 T = 78$ h), and Sb-127 ($1/2 T = 3.85$ d). The indicator isotope I-131 and its uptake in pathways to human consumption is also characteristic of plume hot zones. Most hot zone deposition would occur downwind from the accident site and would be highly associated with rainfall events. While the source term of a quick release accident may only last a few hours or less, hot zone deposition will be a function of wind direction. As illustrated by the Chernobyl plume pathway, impacted communities receiving high levels of I-131, Cs-137, and the many other isotopes associated with a nuclear accident can be several hundred kilometers or more from the accident site. In the case of the Pilgrim Nuclear Generating Station in Plymouth, MA, an accident occurring when prevailing winds are blowing from the southeast, as is typical in the spring and summer, plume hot zone fallout levels above $37,000 \text{ Bq/m}^2$ (1 curie/km^2) of Cs-137 or I-131 or both could extend throughout eastern New England as far as northern Vermont, New Hampshire, and central Maine. With respect to the accident in Japan, prevailing winds brought most of the tropospheric fallout over the Pacific, but brief shifts in wind

direction also contaminated areas up to 75 km in all directions from the facility with contamination in excess of the 37,000 Bq/m² level of concern.

- Extended fallout zones: The extent of the impact of the Chernobyl accident was a surprise to many nuclear accident experts who had predicted that significant fallout would be limited to within ten miles of the accident site. Revised US NRC guidelines now postulate a 50 mile radius of biologically significant amounts of radiation dispersal, which might be the subject of exposure via the ingestion pathway. In the case of the Chernobyl accident, biologically significant quantities of accident fallout were documented in excess of 1,000 miles from the accident site. Global transport of accident-derived nuclides was documented in the 9 to 14 day range. See *Section VIII. Chernobyl Fallout Data* for a detailed listing of accident surveillance reports from many nations.

I-131 as an Indicator of Fissile Activity

In a normal nuclear reaction involving the fission process, I-131 is produced as a volatile component of fissile activity (the fission process) at a rate of 35 to 50 times that of Cs-137. In the case of a loss of coolant accident in a spent fuel pool that had no fissile activity for sixty days, there would be no detectable I-131 activity in comparison to Cs-137 emissions, which would be the prevailing volatile indicator isotope in any source term release. The presence of I-131 in any accident plume is indicative of either ongoing fissile activity (continued criticality or resumed fissile activity) or of recent fissile activity. The Chernobyl Cs-137 source term was 2.7 million Ci or 100,000 terabecquerels; according to the IAEA, the Chernobyl I-131 source term was 85,860,000 Ci or 3.12% that of the I-131 source term (Fairlie 2006). Of interest is the recent NISA assertion that the Chernobyl I-131 source term was 5.2 million terabecquerels or 140,400,000 Ci. While the source of this information is unknown, it was cited to illustrate the fact that Fukushima Daiichi releases of I-131, which Japanese authorities estimated was between 370,000 and 630,000 Ci, were much less than that at Chernobyl (*Wall Street Journal* April 12, 2011). Of particular note with respect to the Fukushima Daiichi MIRE is that a significant portion of the accident source term involved releases of fission products from spent fuel assemblies that had no fissile activity for 60 days or longer. I-131 releases, therefore, were proportionately less in comparison to Cs-137 releases due to the radioactive decay of I-131 in the fuel assemblies in the spent fuel pools that suffered loss of coolant accidents. Resumption of fresh activity within the melted spent fuel pools would be accompanied by renewed I-131 emissions.

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1997 Revised FDA Radioactive Contamination Guideline: Part 2

ATSDR Toxicological Profile for Ionizing Radiation

MARSSIM Draft Multi-Agency Radiation Survey and Site Investigation Manual (EPA, NRC, DOE)

Post-Chernobyl National Safety Guidelines for I-131 in Milk (WHO 1986)

The following WHO summary provides a selection of radiation protection guidelines in effect in Europe for I-131 at the time of the Chernobyl accident:

National Safety Guideline		
Country	becquerels/liter	picocuries/liter
Soviet Union	2,000	54,000
Poland	1,000	27,000
Sweden	2,000	54,000
Romania	185	4,975
Austria	370	10,000
Czechoslovakia	1,000	27,000
West Germany	500	13,500
Switzerland	3,700	99,900
Yugoslavia	-	-
Turkey	-	-
United Kingdom*	2,000	54,000
United States	555	15,000
Italy	500	13,500

- These diverse guidelines compare with the FDA/FEMA emergency PAG for domestic nuclear accidents which are 150,000 pCi/liter I-131 in milk for infants and 2,000,000 pCi/l I-131 in milk for adults.
- Following the Chernobyl accident, much controversy surrounded the temporary radiation standards of 600 Bq/kg set for radiocesium in the general food supply in the European community, which were finally set at 1,000 Bq/kg (= 60,000 cpm) for dairy products and 1,250 Bq/kg for other commodities, by the European Commission in May of 1987. The radiocesium limits for Britain were set at 1,000 Bq/kg for all imported foods. The 1987 guidelines are the ones currently in effect.
- For more information on I-131 and milk see NCI's 1997, *Estimated exposures and thyroid doses received by the American people from Iodine-131 in fallout following Nevada atmospheric nuclear bomb tests* and our special appendix: Contaminated milk: A paradigm (<http://www.davistownmuseum.org/cbm/RadxMilk.html>).

US Radiological Environmental Monitoring Reports (REMPs)

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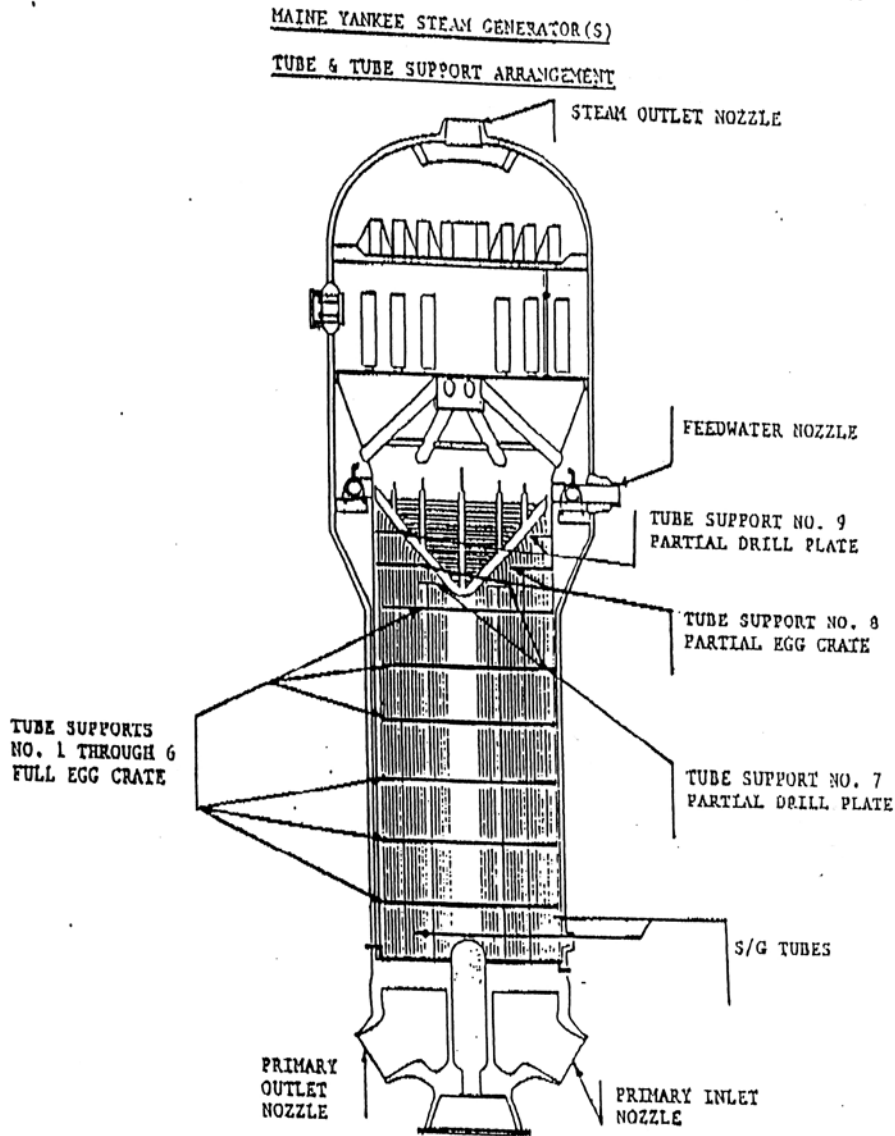


FIGURE 1

Figure 3. Maine Yankee steam generator(s) tube and tube support arrangement (NRC Figure 1).

“Laboratory testing of sleeving joints (between alloy 600 and 690) consistently produces cracking in the weld-heat affected zone of the parent tube.” (Nuclear Regulatory Commission 1995b)

1. Circumferential crack growth in the Maine Yankee steam generator tubes results primarily from primary water stress corrosion cracking (PWSCC) and cannot be predicted from simulated testing. Other processes contributing to the damage in the tubes include “outside diameter stress corrosion cracking (ODSCC), intergranular attack (IGA), pitting, denting, and vibration induced wear” (U. S. Nuclear Regulatory Commission 1995c).
2. Inserting and welding the new sleeves to repair the circumferential cracks in the 16,000 steam generator tubes in the Maine Yankee steam generator creates residual stresses in the sleeve-tube transition area which then must be heat treated to repair stress damage.
3. Both the sleeve insertion and the heat treatment to repair damage caused by the sleeve insertion create additional “far field post-weld stress in the parent tube structure” (U. S. Nuclear Regulatory Commission 1995c).
4. Hard rolling the sleeve edges after insertion is an additional source of residual stress damage. To minimize this damage, hard rolling the sleeve edge is done after heat treatment of the damaged weld, but remains a source of both post-weld transition area stress and far field stress damage.
5. Extensive sludge deposits have been documented by the NRC and MYAPC throughout the steam generator. The largest deposits are at the base of the steam tubes at the junction of the tube sheet. Other sludge deposits are associated with the nine horizontal (“eggcrate” and drill plate) supports. The new sleeves (12, 20 and 30 inch) are located at the intersection of the steam tubes and the tube sheet, well below areas of sludge deposits and stress which have accumulated at these horizontals. The areas of sludge deposits and stress located at these horizontals are not subject to repair in the sleeving process. Not all parent tubing subject to circumferential cracking or other corrosion will be sleeved.
6. MYAPC locked support mock-up tests indicate that sludge deposits combine with copper scaling on the steam tubes to create a locking effect at the horizontal “eggcrate” supports which results in both severe bowing and tube displacement off the vertical during the post-weld heat treatment process (see NRC Figure 2 & Figure 3). The MYAPC report indicates that tube bowing and lateral displacement (deformations) occur early in the stress relief process.

7. Shorter 12-inch and 20-inch sleeves are frequently used in areas with the least sludge deposits to lower the frequency of post-weld induced deformations. The sludge deposits, tube scaling, and other corrosive products result in the non-uniform distribution of pressure and temperature which cannot be quantified in pre-test mock-up trials. "Sleeve joint life will be maximized if the joints are made above the sludge pile" (Nuclear Regulatory Commission 1995b).
8. Extensive copper scaling tube deposits project above the sludge deposits, sometimes overlapping into the weld transition areas and complicating the distribution of operational, weld, and post-weld heat treatment stress damage (see NRC Figure 2).
9. Additional mechanisms causing microstructural degradation of the older parent tubes are not fully understood and cannot be empirically reproduced in mock-up tests. "Recent experience at operating plants has emphasized the sensitivity of the Alloy 600 parent steam generator tube material to stress corrosion cracking when unfavorable residual stresses are introduced by processes such as sleeving" (MYAPC 1995).
10. The formation of both sludge deposits and copper scaling tube deposits result from corrosion processes which are also not fully comprehended. Use of the alloy 690 in the new sleeves, which has twice as much chromium as the parent tube alloy 600, doubles corrosion resistance of the new sleeve. The older less corrosion resistant parent tube continues to be the weakest link in a steam generator being subject to all the degradation processes noted in Section 1, as well as the residual stresses from the sleeving process.
11. Welding during the sleeve insertion results in copper scale tube flaking, further increasing sludge deposits and complicating residual stress distribution.
12. Maine Yankee and Westinghouse steam corrosion tests "indicate a properly stress relieved weld has four to five times the expected life of a comparable weld joint" (Nuclear Regulatory Commission 1995c). All 16,000 welds therefore must be carefully and successfully heat treated to complete a safe sleeving.
13. Ultra sonic testing to analyze tube sleeve welds results in extensive "attenuated backwall signals" due to the copper scaling tube deposits and other corrosive products outside the tube, making it impossible to verify the success of the welds. "Effectiveness of post-weld heat treatments in relieving residual stresses created by the welding process is unknown" (Nuclear Regulatory Commission 1995b).
14. The MYAPC report concludes that "tube OD (outside diameter) deposits can attenuate backwall signals in structurally acceptable welds." Since successful

welds can therefore not be verified with the ultra sonic tests, there is no way to locate defective welds.

15. Defective welds can only be verified by a tube-by-tube preoperational safety analysis. Such a detailed safety check is too time consuming and thus extremely expensive for the licensee, Maine Yankee, in that it would significantly delay the reopening of the plant. The verification of the weld efficacy will only be made as the steam generator is returned to service, or after the first cycle of operation through the use of ECT (eddy current testing).
16. Only full operation of the steam generator will verify the extent of weld deficiencies, far field stress damage, and other structural degradations, including bowing and lateral deformations, as well as additional operational corrosion damage. The confirmation of such damage will only come in the form of leaks or breaks in the steam generator tubes, some types of which could lead to a serious nuclear accident.

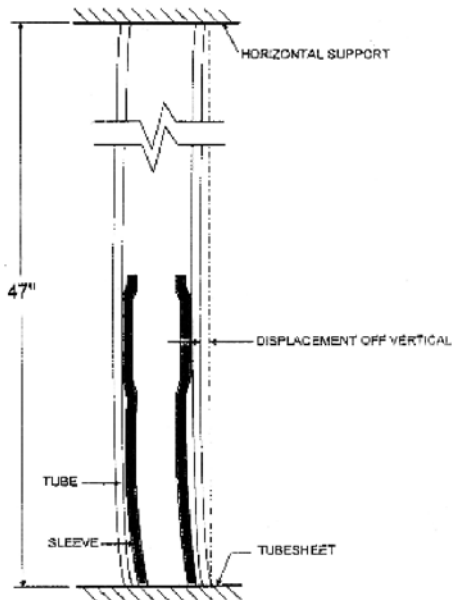
The NRC issued the following reassurances in the September 14th report:

- A. Tube bowing and tilting (deformations) resulting from the locking effect of the sludge deposits “might result in tube contact, but there are no indications such contacts will be hazardous” (Nuclear Regulatory Commission 1995c). This is an extraordinary admission of steam tube degradation.
- B. “Local deformations have equal or better corrosion resistance than the stress relieved joints” (Nuclear Regulatory Commission 1995c). In view of the superior corrosion resistance of the new sleeve, the sleeve tube transition area remains that component of the steam generator most vulnerable to a catastrophic failure.
- C. “Sleeving induced deformations and resulting stresses in the Maine Yankee steam generator tubes, should a tube be locked at a horizontal position [by sludge deposits], will be low enough to insure a satisfactory sleeve performance through Maine Yankee's life” (Nuclear Regulatory Commission 1995c). This controversial assertion, which is clearly contradicted in the MYAPC Locked Support Testing Program report, can never be verified empirically: safe operation of this damaged generator through the year 2008 would be an extraordinary stroke of good luck.

Safety Issue Summary: The NRC and MYAPC locked tube test program clearly documents a grossly degraded steam generator with extensive steam tube circumferential cracking due to primary water stress corrosion cracking (PWSCC) and widespread accumulations of sludge deposits (corrosion products) throughout the steam generator. The steam generator suffers additional system wide welding-induced stress damage during the sleeving process, which must be successfully repaired with a post-weld heat treatment process which in itself either reinforces pre-existing far field stress

damage in the parent tube or extends the damage further down the parent tube. The successful operation of the repaired steam generator is further undermined by steam tube deformations (bowing and vertical displacement) which occur in the repair process due to extensive preexisting corrosion-derived sludge and copper scale tube deposits.

BOWED 30" SLEEVE TUBE & WITHOUT SUPPORT "IF FIXED"



TUBE SCALE COPPER CONTENT

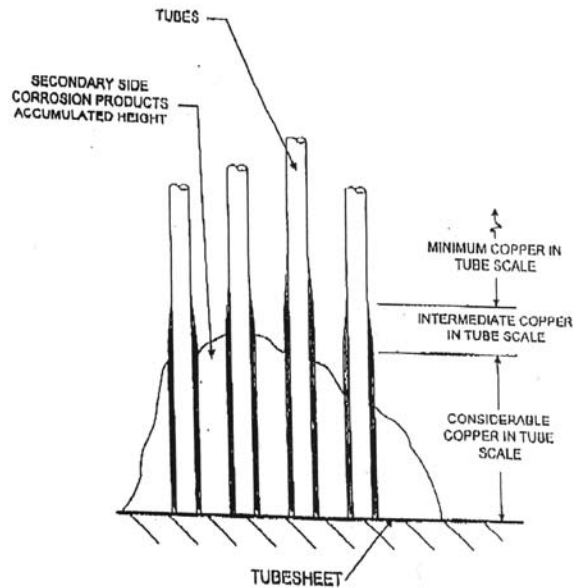


Figure 2

Figure 4. Fuel assembly deformation (NRC Figure 3 [left] and Figure 2 [right]).

These deformations cannot be repaired. The sludge deposits and scaling are located throughout the steam generator, with a particularly large accumulation of corrosion products (see NRC figure 2) at the tube sheet intersection and smaller deposits at the horizontal supports. These widespread sludge deposits combined with tube scaling render tests to verify weld efficacy useless.

The sleeving process, which includes the plugging of some steam tubes that cannot be successfully welded, results in a reduction in the reactor coolant flow rate. Future plant operation may approach, equal, or exceed the 9 percent reduction in maximum power which is the cutoff point for the safe operation of the Maine Yankee plant. This reduced reactor coolant flow, combined with possible weld deficiencies, sludge deposits, and microstructural degradation, provide the basis for Maine Yankee's recent controversial application for a reduced power license. The unprecedented restart of such a degraded and decrepit facility is a dangerous experiment which poses a clear and present danger to the public safety in the State of Maine.

The return of this degraded equipment to service in lieu of replacement with a new steam generator greatly increases the chance of a substantial nuclear accident and constitutes an act of criminal negligence by the NRC, the supervisory agency for this obsolete and dangerous nuclear energy dinosaur.

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