June 1, 2020

Office of the Secretary
United States Nuclear Regulatory Commission
Washington, DC 20555-0001
Attention: Rulemaking and Adjudications Staff
Submitted by e-mail to Rulemaking.Comments@nrc.gov

I respectfully submit the enclosed petition, dated June 1, 2020, for rulemaking pursuant to §2.802 in Title 10 of the Code of Federal Regulation. The petition seeks to have the U.S. Nuclear Regulatory Commission amend, as needed, its requirements (10 CFR 50.47, Appendix E to Part 50), implementation guidance and supporting analysis, materials and activities such that protective actions implemented during a General Emergency at a nuclear power plant will most likely do more good than harm when both the possible physical health effects of radiation exposure and protective actions are taken into consideration.

This is the second request on this general topic. I was informed by the NRC[1] on May 12, 2020, that my first request, sent March 10, 2020, would not be docketed because NRC does not have the authority to implement one of the requested changes. Specifically, with regard to amending NRC regulations to address mental health effects expected from a General Emergency at an NPP. In addition, the NRC pointed out, that while not required for docketing, it would assist the NRC in its evaluation of my petition if I explained why rulemaking is the most favorable approach to address the problem.

This request for rulemaking addresses these issues by: 1) removing the request for rulemaking regarding mental health effects expected from a General Emergency at an NPP and 2) providing an explanation why rulemaking is the most favorable approach to address the problem.

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Attached: June 1, 2020 Petition for Rulemaking to ensure that the response to protect the public in the event of a General Emergency at a nuclear power plant (NPP) does more good than harm

[1] By email on May 12, 2020 from Cindy Bladey, Chief Regulatory Analysis and Rulemaking Support Branch, with an attached letter from John R. Tappert, Director Division of Rulemaking, Environmental, and Financial Support Office of Nuclear Material Safety and Safeguards

June 1, 2020

Petition for Rulemaking to ensure that the response to protect the public in the event of a General Emergency at a nuclear power plant (NPP) does more good than harm

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Background: I have worked in emergency preparedness and response for about 40 years at both US NRC and International Atomic Energy Agency (IAEA). I am one of the authors of the guidance (NRC and FEMA 1996) on protective actions in the event of a General Emergency.

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I Introduction

I.1 The request

I feel obligated to make this request being one of the authors of the potentially harmful Nuclear Regulatory Commission (NRC) guidance (NRC and FEMA 1996) on public protective actions in the event of a General Emergency. My analysis indicates that taking protective actions in accordance with NRC requirements (10 CFR 50.47, Appendix E to Part 50) and guidance (NRC and FEMA 1980, 1996, 2011, 2019) during a General Emergency[1] at a nuclear power plant (NPP) will likely result in far more deaths as a consequence of those actions, than could have resulted from radiation exposure.

This petition for rulemaking, made pursuant to 10 CFR Part 2.802, requests the NRC to amend, as needed, its requirements (10 CFR 50.47, Appendix E to Part 50), implementation guidance (NRC and FEMA 1980, 1996, 2011, 2019) and supporting analysis (e.g. NRC 2013a, 2013b), materials and activities such that public protective actions implemented during a General Emergency at a NPP will most likely do more good than harm when both the possible physical health effects of radiation exposure and protective actions are taken into consideration.

This document is written for both NRC technical staff and stakeholders (e.g. public and public officials) with the goal of providing a common understanding of the issues, and thus a basis for informed comments. First, I provide the basis for my assessment, summarize the problem and review relevant experience from the FDNPP accident. Next, I provide my estimates of the deaths due to radiation exposure and protective actions, followed by my estimates of the deaths caused by a response to a General Emergency under NRC requirements and guidance. Finally, I distinctly state the problem and possible solution regarding NRC requirements, implementation guidance and supporting analysis, materials and activities concerning protection of the public during General Emergencies. I also provide a short glossary of important terms used in this document.

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[1] A General Emergency is declared for *"actual or imminent substantial core degradation or melting with potential for loss of containment integrity or hostile action that results in an actual loss of physical control of the facility"* (NRC 2020a*).* These are the conditions that could cause radiation-induced health effects off-site.

I.2 Basis for my assessment

Typically the health risks of radiation exposure are expressed in terms of relative risks[2] or excess relative risks. However readers, even experts, often overestimate (Noordzij 2017) the importance of health effects when presented in these terms. Absolute risk, the number of events (e.g. excess deaths) divided by the number of people in the affected groups[3], has been found to be the most understandable way to communicate risk (Noordzij 2017). Therefore, I express the health risks of radiation exposure and protective measures in terms of absolute risk of excess deaths to allow easy and balanced comparison.

The goal is to realistically compare and balance the health risks from both radiation exposure and protective actions in the event of a General Emergency. I therefore use best estimates and not so-called 'conservative estimates[4]' in my analysis of the health effects of both radiation exposure and protective actions. Use of such "conservative estimates" can actually result in increased hazards for the public by triggering unwarranted[5] and harmful protective actions. In this connection, I assume for my analysis a "*Representative General Emergency*"[6] that has projected excess offsite radiation-induced deaths representative of those for the important NPP emergencies (core damage scenarios) (NRC 2012a, 2013a, 2013b) and not the accident scenarios with the greatest projected excess deaths which are far less likely.

I.3 Summary of the problem

FDNPP accident experience (e.g., Hasegawa 2016, IAEA 2015a, NAIIC 2012 Tanigawa 2012) and subsequent early analysis (e.g., Callen and McKenna 2018) indicates that the protective actions taken in accordance with NRC requirements (10 CFR 50.47, Appendix E to Part 50) and guidance (NRC and FEMA 1980, 1996, 2011, 2019) during a General Emergency could result in far more excess deaths than from radiation exposure. Therefore the fundamental tenet of this petition is that the response during a General Emergency should be justified[7], meaning that it should do more good than harm. The protective actions taken should not result in more excess deaths than the radiation exposure they are intended to prevent. Contrary to this fundamental tenet Figure 1 and Figure 2 show that protective actions triggered by declaration of a General Emergency, in accordance with NRC guidance, may cause 12 times more excess deaths among the public and 15 times more excess deaths among elderly residents of care facilities than caused by radiation exposure during a representative General Emergency[8]. The disparity could be even greater when protective actions are taken based on EPA Protective Actions Guides (PAGs)[9], which is an integral part of the NRC protective action guidance, or based on dose criteria lower than the EPA PAGs as established by some States. The one radiation-induced cancer death possibly prevented by the protective actions is described in Figure 1 as theoretical; since, it will not be discernible, even after careful study of many thousands of exposed individuals over their lifetimes. However most of the deaths caused by the protective actions, shown in Figure 2, will be clearly discernible within months to a few years, as occurred during the FDNPP accident. I recognize that my estimates are uncertain and based on

[2] Relative risk is the ratio of health effect rates of two differently affected groups (e.g. exposed and not exposed) (UNSCEAR 2018).

[3] For example, there were about 15 excess deaths per 500 elderly residents dislocated from care facilities during the FDNPP accident.

4 e.g., assuming the worst radiological health effects theorized

[5] In terms of the health risk from radiation exposure.

[6] See Glossary.

[7] A fundamental principle of radiation protection according to the National Council on Radiation Protection and Measurements (NCRP) (Kase 2004) and ICRP (ICRP 2007) is justification. Where justification is assuring *"Any decision that alters the radiation exposure situation should do more good than harm."* (ICRP 2007)

[8] See section *'IV.3 Phase 1 – Impact on mortality of protective actions taken upon declaration of a General Emergency'*

[9] A PAG is a projected dose at which specific protective actions are recommended – See Glossary and section '*IV.4 Phase 2 - Impact on mortality of protective actions taken where doses are projected to exceed the EPA PAGs'*

limited analysis and data; nevertheless, they indicate that the NRC regulations and guidance on protective actions during a General Emergency need to be carefully reexamined.

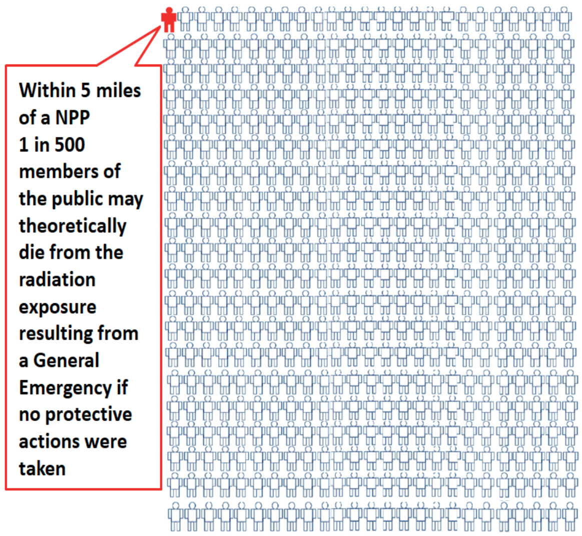

Figure 1 Estimated excess deaths per 500 people within 5 mile of a NPP caused by radiation exposure resulting from a representative General Emergency if no protective actions were taken.

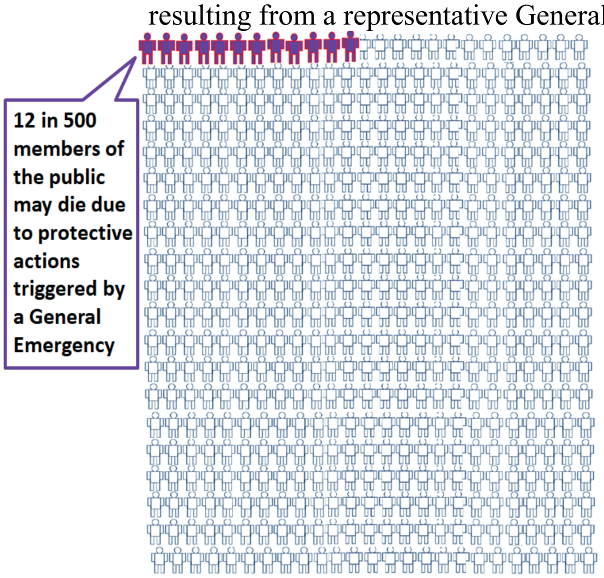

Figure 2 Estimated excess deaths per 500 (public and elderly care facility residents) within 5 miles caused by protective actions triggered by declaration of a General Emergency in accordance with NRC guidance.

I.4 Fukushima accident experience

The FDNPP accident started on March 11 2011 at about 15:30 when a tsunami caused loss of the electrical power needed to keep the reactor cores cool. Under the NRC classification system this would have been a General Emergency. The first reactor core was estimated to have started melting about 2 hours later. Several days later, on March 15-16, there was a major release lasting about 24 hours. This release was neither predicted nor monitored at its source. The wind direction changed 360 degrees during the release and there was substantial deposition of radioactive material on the ground in one direction when the plume encountered rain (IAEA 2015a, 2015b). The areas near the NPP were evacuated or sheltered initially due to concerns about conditions in the NPP and after the March 15 release areas were evacuated (relocated) based on environmental monitoring (Callen and McKenna 2018, IAEA 2015a, 2015b). This protective action strategy is similar to that in NRC guidance for General Emergencies (NRC and FEMA 1996, 2011).

The FDNPP accident is not expected to result in any discernible radiation-induced health effects among the public off the site (UNSCEAR 2014, 2016). However, the dislocation of about 140,000 people[10] (Fukushima Prefectural Government 2019) caused principally by evacuation and sheltering[11], resulted in hundreds of deaths, adverse long term health conditions (e.g. hypertension), adverse lifestyles (e.g. loss of community ties), and immense economic and property losses (e.g. loss of homes) (Hasegawa 2015, 2016, Hayakawa 2016). Clearly the protective actions taken during the FDNPP accident were a greater threat to public health than the radiation exposure.

Consequences similar to those observed during the FDNPP accident can be expected in the US in the event of a General Emergency. Protective action consistent with NRC guidance taken during a General Emergency could result in excess deaths even though there would be no discernible excess radiation-induced deaths among the public. Consequently, the most likely cause of excess deaths during a General Emergency would not be radiation exposure but protective actions taken in accordance with NRC requirements and guidance.

Numerous authors, following the FDNPP accident, have emphasized that the health effects of protective actions (e.g. evacuations) need to be considered in planning for severe NPP emergencies (i.e. General Emergencies). For example, a general finding of the 2015 Health Physics Society symposium on health risks from low doses and low dose-rates of ionizing radiation was:

> "*A decision to implement protective actions for public health (e.g., evacuations) in the event of low dose exposure must be carefully justified to ensure that the actions provide public benefit and do not result in harm."* (Brooks 2016).

This need is illustrated by the experience of Mr. Yamauchi, an evacuee of the FDNPP accident:

> *"So the family moved to the Japanese capital, 200km away, which is where their troubles really began. For the past seven years they have struggled with cramped conditions, money troubles, bullying at school, … I'm still taking pills for high blood pressure*" (Harding 2018).

II Radiation-induced health effects important during a General Emergency

II.1 Early radiation-induced health effects

The first priority of emergency response traditionally has been the reduction/ prevention of early radiation-induced health effects[12] (NRC 1978) in tissues or organs. Early radiation-induced health effects typically occur due to high doses received over days or less (acute dose) and typically are seen within months of exposure. The early radiation-induced effects that may be important (IAEA 2005) during a

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[10] About 40,000 people have not yet returned (Fukushima Prefectural Government 2019).

[11] During the FDNPP emergency people evacuated (dislocated) from areas where sheltering was advised for several reasons: 1) uncertainty because there was no predesignated zone for sheltering, 2) some local governments ordered evacuation of their towns located within the 20 to 30 km before the national government advised sheltering on March 15 (NAIIC 2012), 3) many residents elected to evacuate on a voluntary basis without waiting for an evacuation order from either national or local government (NAIIC 2012) and 4) those remaining in sheltered areas evacuated within about a week due to loss of essential services (e.g. food, fuel) (Hasegawa 2016).

[12] Early radiation-induced effects are also called deterministic effects, acute effects, prompt effects, and tissue reactions.

General Emergency are shown in Table 1. However, the latest NRC analysis (NRC 2012a, 2013a, 2013b) did not appear[13] to project doses sufficient to cause any of these effects beyond the immediate NPP boundary for the representative General Emergency. Obviously this needs to be confirmed by further analysis in particular concerning the early effects to the fetus.

Table 1 Threshold, exposed group and early radiation-induced health effects possibly important for General Emergencies

Threshold dose rem (mSv)[a, b]	**Exposed**	**Early radiation-induced health effect**
300 rem (3 Gy)	Public	Death due to red bone marrow exposure
100 rem (1 Gy)		Non-fatal effects – permanently suppressed sperm counts[c]
10 rem (0.1 Gy)	Pregnant women (Embryo/fetus)	Reduction in IQ [d]

a. Threshold dose is the dose at which 5% of those exposed would be expected to suffer the effect (IAEA 2005).
b. The dose at which early effects occur should be provided in terms of absorbed dose (Gy), however, effective dose (rem) is used for the US criteria for taking protective actions. Therefore, to allow for a direct comparison with US criteria, I assume the numerical value in absorbed dose (Gy) corresponds to or is lower than the equivalent numerical value in effective dose (rem) for exposure from an NPP release during a General Emergency. Keeping the effective dose numerical value below the thresholds for early effects (given in Gy) should ensure the associated early health effects will not occur. This is supported by an examination of the dose factors for I-131 and Cs-137, which are major sources of dose for light water reactor NPP releases (EPA 1988, 1993, ICRP 2002).
c. Keeping the dose below this dose should prevent other important non-fatal early effects among the public.
d. ICRP concluded for fetal doses of less than 0.1 Gy (10 rem) there is no medical justification for terminating a pregnancy due to radiation exposure (ICRP 2000).

II.2 Late radiation-health effects (cancers and genetic effects)

Late radiation-health effects[14] occur by chance and the probability they will occur is proportional to the dose (i.e. the higher the dose the higher the probability). They include cancers and genetic effects in off-springs. The risk of radiation-induced genetic effects is very small compared to the risk of radiation-induced cancers.

Radiation-induced cancer deaths and thyroid cancers are the principal late radiation health effects of concern during a General Emergency. However thyroid cancers are not addressed in this petition in part because the latest NRC study of NPP emergencies (NRC 2013a) does not provide estimates of thyroid cancer rates and subsequent health effects. Nevertheless, thyroid cancers should be considered in any later examination of radiation-induced health effects.

I estimated the risk of excess radiation-induced cancer deaths, as is typically done, using the linear-non-threshold (LNT) model[15]. This model assumes the risk of excess radiation-induced cancer deaths is linearly proportional with the dose and projects excess risk to zero dose. Therefore, it projects cancer deaths at doses below 10 rem (100 mSv) at which excess cancers are not consistently discernible even after careful study of many thousands of exposed individuals over their lifetimes (ICRP 2005, NRC 2019, Shore 2019, UNSCEAR 2011). Thus I refer to radiation-induced cancer deaths projected by the LNT

[13] The only estimates of early organ or tissue dose provided in the latest NRC study (NRC 2013a) were for the red bone marrow to the closest resident which for the representative General Emergency was about 0.1 gray (Gy). I assume that the acute dose to the reproductive organs and fetal brain from an NPP release (e.g. I-131, Cs-137) is similar to or lower than the acute red bone marrow dose (EPA 1988, 1992, ICRP 2002).
[14] Late radiation-induced health effects are also called stochastic effects, latent effects, and delayed effects.
[15] Assuming a lifetime risk of fatal cancer (fatal radiation risk coefficient) of 5 % (ICRP 2007) at 100 rem (1 Sv) or 25 excess deaths per 500 members of the public.

model at doses below 10 rem (100 mSv) as “theoretical”. EPA has referred to them as “statistical deaths” (EPA 1992).

The projection of cancer deaths at low doses using the LNT is often considered prudent (ICRP 2007); however, this is only prudent if it results in actions that do more good than harm as emphasized here. The International Commission on Radiological Protection (ICRP) (ICRP 2007) states *“Any decision that alters the radiation exposure situation should do more good than harm”* and one of the principles in establishing the EPA PAGs (EPA 2017) was *“Balance protection with other important factors and ensure that actions result in more benefit than harm”.* However, as will be shown, this principle was seldom applied when establishing NRC or EPA guidance concerning protective actions.

Table 2 shows per rem and mSv the approximate excess radiation-induced cancer deaths per 500 for the public based on the LNT model. The table also shows the total cancer deaths per 500 including the normal US lifetime cancer death rate. The shaded values are theoretical as they are for doses at which excess radiation-induced cancer deaths would not be discernible. Figure 3 shows the approximate excess radiation-induced deaths per 500 members of the public projected at 10 rem (100 mSv) based on the LNT model and the total cancer deaths expected among the exposed public including the normal cancer death rate in the US.

Table 2 Approximate excess radiation-induced cancer deaths (late deaths) per 500 members of the public per rem and mSv based on LNT model and total cancer deaths expected among those exposed including normal US lifetime cancer deaths.

Exposure		**Excess radiation-induced cancer (late) deaths per 500[a, b] exposed members of the public**	**Total cancer deaths per 500[b, c] among exposed members of the public (excess radiation-induced + normal)**
rem	**mSv**		
0	0	0.0	125
0.1	1	0.02	125
0.5	5	0.1	125
1	10	0.2	125
2	20	0.5	125
5	50	1	126
10	100	2	127
20	200	5	130
50	500	12	137
100	1000	25	150

a. Estimated excess cancer deaths per 500 members of the public exposed to radiation based on the LNT model using the ICRP fatal radiation risk coefficient of 5% (25 deaths per 500 exposed) at 100 rem (1 Sv) (ICRP 2007).

b. The shaded values are considered theoretical as they are for doses at which radiation-induced cancers would not be discernible. According to United Nations Scientific Committee on the Effects of Atomic “*Statistically significant elevations in risk are observed at doses of 100 to 200 mGy and above and epidemiological studies alone are unlikely to be able to identify significant elevations in risk much below these levels*” (UNSCEAR 2011).

c. Total cancer deaths expected among the exposed public including the normal lifetime US cancer death rate of about 25% (125 lifetime deaths per 500) (ACS 2019).

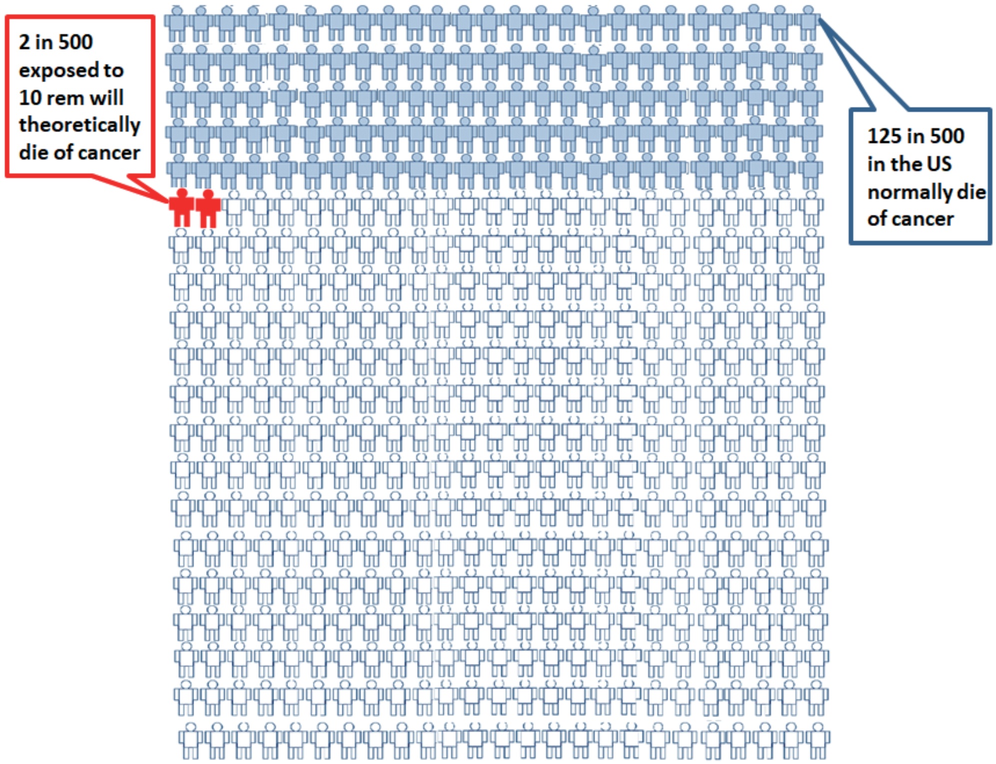

Figure 3 Approximate excess radiation-induced cancer deaths (late deaths) per 500 members of the public exposure to 10 rem (100 mSv) and those in the US who normally die from cancer.

Table 3 shows my estimate of the radiation-induced cancer deaths per 500 members of the public within 5 and 10 miles of a NPP for the representative General Emergency assuming no evacuation. My estimates were based on the latest NRC studies of NPP accidents (NRC 2012a, 2013a, 2013b). I estimate that the representative General Emergency will cause about one excess radiation-induced cancer death per 500 members of the public within 5 miles of the NPP and this death is considered theoretical; since it would not be discernible even if it occurred.This risk is also more than 100 times smaller than the normal lifetime cancer death rate in the US, which is about 125 per 500 members of the public (ACS 2019).

Table 3 Estimated risks of radiation-induced cancers per 500 members of the public within 5 and 10 miles of the NPP without evacuation for the representative General Emergency

Distance from the NPP (within)	**Risk of radiation-induced cancer deaths per 500 without protective measures for the representative General Emergency[a]**
5 mile radius	1 (theoretical death)[b]
10 mile radius	0.2 (theoretical death)[b]

a. Based on LNT model projected mean individual latent cancer risk (LCR) for the representative General Emergency (Long-Term Station Blackout (LTSBO)) from the latest NRC NPP accident study (NRC 2013a). The LCR estimates for the early phase of the response in the latest NRC NPP accident study (NRC 2013a) assumed most of the people within 10 miles evacuated before the plume arrival. Therefore I needed to estimate LCR within 10 miles without evacuation based on the LCR estimate for 20 miles (NRC 2013a) adjusted to account for the increase in release concentration at 5 and 10 miles assuming average dispersion (D stability class) (NRC 1978).
b. Considered theoretical because they would not be discernible.

It is important to note that the normal (i.e. not involving radiation exposure from an emergency) cancer rates among the public can vary 2 % (10 per 500) or more (Smith 2007) due to factors such as location (e.g. urban, non-urban) and lifestyle (e.g. diet, smoking). In turn, these factors can be influenced by implementation of protective actions. Therefore, careful consideration should be given to the implementation of protective actions intended to reduce doses below about 10 rem; since, they could actually result in a discernable increase in the cancer rate (i.e. as a result of change in location or lifestyle choices).

III. Physical health effects due to protective actions

III.1 Introduction

The protective measures called for in NRC guidance (NRC and FEMA 1980, 1996, 2011, 2019) and supporting EPA guidance (EPA 1992, 2017) include evacuation, preparation to evacuate, sheltering, relocation and restrictions on food and drinking water. Evacuation refers to the urgent removal of people from an area and relocation refers to long term removal (e.g. a year or more). Dislocation, while not a protective action, can be a consequence of any of these protective actions and refers to people moving to and residing in a different location. Dislocation was the primary cause of hundreds of deaths and other health effects among the public during the FDNPP accident. The physical health effects caused by the protective actions and resulting dislocations are summarized in Table 4 (Callen and McKenna 2018).

Table 4 Summary of the physical health effects resulting from implementation of protective actions

Physical health effect	Protective action
Deaths	• Evacuation: ○ of patients without needed support. ○ under life threatening conditions (e.g. dangerous road/weather conditions). • Any protective measures (e.g. sheltering) resulting in dislocation.
Health effects (e.g. diabetes) or lifestyle changes (e.g. smoking) resulting in increased mortality or reduced quality of life.	• Any protective measures resulting in dislocation.

Source: (Callen and McKenna 2018).

III.2 Shelter and preparation to evacuate

Sheltering and instructions to prepare to evacuate within an area could cause deaths and other adverse health effects if they result in dislocations[16] or a failure to provide needed support. During the FDNPP accident the death rate among vulnerable patients sheltered in a hospital without needed support (e.g. no heating, staff shortages) was about 2-3 times higher than for those who were evacuated with needed support (Shimada 2018).

[16] During the FDNPP emergency people evacuated (dislocated) from areas where sheltering was advised for several reasons: 1) uncertainty because there was no predesignated zone for sheltering, 2) some local governments ordered evacuation of their towns located within the 20 to 30 km before the national government advised sheltering on March 15 (NAIIC 2012), 3) many residents elected to evacuate on a voluntary basis without waiting for an evacuation order from either national or local government (NAIIC 2012) and 4) those remaining in sheltered areas evacuated within about a week due to loss of essential services (e.g. food, fuel) (Hasegawa 2016).

III.3 Travel (movement) during evacuation and relocation

Travel during evacuation, under most conditions, is as safe as normal road travel. However, deaths have resulted during travel under hazardous conditions and when needed medical support was not provided.

The evacuation of about 800 elderly patients and nursing home residents during the FDNPP accident resulted in about 50 deaths during or shortly after their movement (Hasegawa 2015, 2016, IAEA 2015a) when needed support was not provided. These deaths were due to factors such as hypothermia, dehydration and deterioration of underlying medical problems (Hasegawa 2016, Tanigawa 2012). However, later evacuations during the FDNPP accident of about 500 patients from hospitals and nursing facilities were carried out without any deaths during or shortly after their movement when the needed support was provided (Hasegawa 2015, 2016).

The studies of 60 US evacuations [17] involving about 15 million people found less than 10 early deaths (NRC 2005, 2008) occurred during travel. This death rate is similar to that during normal road travel in the U.S. However, travel during the Hurricane Rita evacuation, involving about 3 million people, resulted in about excess 100 early deaths. This evacuation involved travel lasting more than 24 hours in temperatures above 100°F. These early deaths resulted from hyperthermia, dehydration, lack of needed medical care and an accident involving 23 nursing home evacuees in a bus fire (NRC 2008; Zachria 2006).

III.4 Dislocation

Dislocation during any emergency (e.g. hurricanes) can cause excess deaths and injuries. Table 5 provides my estimates of the excess death rates due to dislocation.

Table 5 Excess death rates (early plus late) due to dislocations

Among:	**Excess deaths per 500 dislocated**
Public (General population)	
• Early deaths (occur within a few years)	7[a]
• Late deaths (occur due to long term medical conditions)	5[a]
• Total	12
Residents of facilities for long stays and the elderly	
• Early deaths	15[b]

a. See section III.4.1 Public (General Population).

b. See section III.4.2 Residents of facilities for the elderly and long stay residents.

III.4.1 Public (General Population)

The 7 excess early deaths per 500 members of the general public dislocated (1.4 %) shown in Table 5 are based on the 2000 disaster related deaths (DRD) [18] among the 147,000 dislocated from Fukushima Prefectures due to the FDNPP accident [19] as of 30 September 2019 (Reconstruction Agency Japan 2019,

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[17] Due to hurricanes, chemical fires, an earthquake, malevolent acts, wildfires, railroad and truck accidents, pipeline ruptures and floods.

[18] DRD is defined as a death caused by the deterioration of underlying medical problems due to poor medical access or illnesses arising from poor living environments, such as temporary shelters, in a disaster" (Hasegawa 2016).

[19] Reference (Reconstruction Agency Japan 2019) provides the DRDs for municipalities of the Fukushima Prefecture, including those not dislocated due to the FDNPP accident. The municipalities that were not dislocated were not included in my estimate.

Saji 2013, Hasegawa 2016, Hayakawa 2016). These dislocations were primarily due to FDNPP accident evacuation and sheltering[16] recommendations. About one tenth of these deaths occurred within a month following dislocation and 90% of the deaths occurred in those over 66 years old (Reconstruction Agency Japan 2019, Hasegawa 2016). The DRD values are uncertain; since they are based on the numbers of cases for which the Japanese Government paid "condolence money" following approval of a committee (Hayakawa 2016) and not supported by analysis of death rates before and after the dislocations (Callen and McKenna 2018). However the large increase in excess deaths during the first month following dislocation confirms there was an increase in the excess death rate due to dislocation.

The excess 5 late deaths per 500 dislocated shown in Table 5 were estimated, as shown in Table 6, based on: 1) the increase in the prevalence of hypertension (high blood pressure), diabetes (high blood glucose) and atrial fibrillation (Afib) (Hasegawa 2016) observed following dislocations during the FDNPP accident and 2) the fraction of those estimated to die due to these medical conditions in 25 years. These estimates are uncertain being based on early data, limited literature review of medical studies and are too recent to be supported by long term studies.

Table 6 Excess prevalence of medical conditions after FDNPP accident dislocations and estimated resulting excess late deaths.

Medical condition	**Excess prevalence in medical condition per 500 after dislocation[a]**	**Fraction projected to die in 25 years due to medical condition**	**Excess late deaths per 500[e] following dislocation due to medical condition**
Hypertension (high blood pressure)	30	0.015[b]	0.5
Diabetes (high blood glucose)	10	0.20[c]	2
Atrial fibrillation (Afib)	5	0.50[d]	2.5
Total			5

a. Following FDNPP accident dislocations (Hasegawa 2016).
b. The excess absolute risk of late deaths due to high normal and stage 1 hypertension in 25 years was found to be 10-20 deaths per 1000 (1-2 %) in young adult men (Miura 2001). I assumed 1.5 % (0.015) excess late deaths over 25 years.
c. Excess late deaths due to diabetes was found to be about 7 deaths per 1000 person-years (Stokes and Mehta 2013) which in 25 years I assumed results in 175 excess deaths per 1000 (7 deaths per 1000 person-years x 25 years) or about 20% (0.20) excess deaths.
d. Among patients between 55-74 years old with atrial fibrillation (Afib) the 10 year excess mortality was found to be about 30 % (Sankaranarayanan 2015). I assumed 50 % (0.50) excess late deaths over 25 years due to Afib.
e. Estimated by multiplying the excess prevalence per 500 by the fraction projected to die in 25 years due to the medical condition.

One study (Morita 2017) compared the early death rates[20] before and after the FDNPP accident for the residents of two cities (Soma and Minamisoma) located around 10–45 km north of the FDNPP. Some residents of these towns were dislocated while others were not; however there was no distinction made between the two groups in the study. The mortality rate among the elderly was three times higher in the first month following the accident than in the year before the accident but no increase was found in subsequent months.

[20] Excluding direct deaths (e.g. drowning, burns) attributed physical force of the earthquake and ensuing tsunami.

III.4.2 Residents of facilities for the elderly and long stay residents

During the FDNPP accident dislocations of the residents of facilities for the elderly resulted in about 15 excess early deaths per 500 residents as shown in Table 5. This resulted from a sharp increase in the death rates among elderly residents within a month of dislocation with increased rates continuing through the first year (Yasumura 2014). During US hurricanes dislocations of long stay residents of nursing homes (Dosa 2012) resulted in about the same rate of excess early deaths. These increased death rates seem to have occurred, despite adequate medical care being provided during and after the dislocations.

III.5 Food and drinking water restrictions

Food and drinking water restrictions could result in dislocations and associated physical health effects if the population could not live long term in the area where such restrictions are in place.

IV Health impact of taking protective actions consistent with NRC requirements and guidance

IV.1 NRC requirements and guidance

Under Title 10 of the Code of Federal Regulations (10 CRF 50.47) an operating license for a NPP requires that a *"finding is made by the NRC that there is reasonable assurance that adequate protective measures can and will be taken in the event of a radiological emergency"*. This determination is based on the NRC's assessment of licensee emergency preparedness and the Federal Emergency Management Agency's (FEMA) assessment of State, local, and tribal governments preparedness (44 CFR 350).
Such findings (i.e. by NRC and FEMA) require meeting the standards in 10 CFR 50.47 and emergency plans that meet the requirements in Appendix E to Part 50. These requirements are very general and in part require provisions to promptly initiate protective actions consistent with federal guidance within a 10 mile radius plume emergency planning zone (EPZ).[21] upon declaration of a General Emergency. The criteria used by the NRC and FEMA for these assessments is principally contained in NUREG–0654/ FEMA–REP–1, Rev. 1 and 2 (NRC and FEMA 1980, 2019).[22] jointly published by NRC and FEMA first in 1980. NUREG 0654 Rev. 1 and Rev 2 (NRC and FEMA 1980, 2019) state that the overall/primary objective of radiological emergency planning is to provide dose savings for a spectrum of accidents/incidents that could produce offsite doses in excess of the current federal protective action guides (PAGs). No mention is made that protective actions should do more good than harm.

The guidance on acceptable strategies for the protection of the public within the plume exposure pathway EPZ in the event of a General Emergency is contained in NUREG-0654/FEMA-REP-1, Rev. 1, Supplement 3 (NRC and FEMA 1996, 2011), also jointly published by NRC and FEMA. There are two versions of NUREG-0654/FEMA-REP-1, Rev. 1, Supplement 3, the first published in 1996 (NRC and FEMA 1996) and the second published in 2011.[23] (NRC and FEMA 2011). Following the guidance in either version appears to be considered acceptable in demonstrating compliance with NRC regulations (NRC and FEMA 2011).

Furthermore FEMA has an ongoing program to insure State, local and tribal governments can adequately implement their emergency plans (44 CFR 350.5). This system is based on NUREG-0654 and its

[21] The size of the plume EPZ (10 miles) was based on the analysis from the 45 year old Reactor Safety Study (NRC 1975) which assumed a much larger release than considered credible today.
[22] FEMA regulations (44 CFR 350.5) cite NUREG-0654 (NRC and FEMA 1980) as the basis for making findings on the adequacy of State, local, and tribal radiological emergency preparedness within the EPZs.
[23] The NRC staff did not expect existing licensees to use the guidance in the 2011 version unless there is a change to its licensing basis (NRC and FEMA 2011).

supplements and described in the FEMA Program Manual Radiological Emergency Preparedness[24] (FEMA 2015). This program includes evaluations of exercises and post exercise public meetings at which the NRC discusses the protective action taken in event of an emergency at the NPP.

NRC requirements and guidance on protective action strategies were based on analysis (e.g. NRC 1975, 1978, 1990) that is, in some cases, more than 40 years old and did not consider either: 1) the health impact of protective actions and resulting dislocations or 2) the latest analysis of NPP emergencies (NRC 2012a, 2013a, 2013b) which project much smaller releases and thus smaller radiation-induced health consequences**.**

IV.2 NRC protective action strategy

The protective action strategies of both versions of NUREG-0654/FEMA-REP-1, Rev. 1, Supplement 3 (NRC and FEMA 1996, 2011) have basically two phases, as summarized in Table 7: Phase 1 when actions are taken upon declaration of a General Emergency, and Phase 2 when protective actions are taken where doses are projected to exceed the EPA PAGs (EPA 2017).

Table 7 Phases of the NRC protective action strategies

Phase	When protective actions are triggered	Typical protective actions
1	Upon declaration of a General Emergency[a]	Evacuation in all directions within 2 miles and sheltering or evacuation within 5 miles downwind, while those within the remainder of 10 mile radius plume exposure pathway EPZ prepare and monitor for further instructions[c].
2	Projection of doses[b] exceeding EPA PAGs	Shelter, evacuation, relocation and/or food and water restrictions as shown in Table 9.

a. With the goal of triggering protective actions that need to be taken before a major release to be most effective.
b. Based on release projections or environmental measurements.
c. The 1996 version of the NRC guidance (NRC and FEMA 1996) recommends evacuation of a 2 mile radius and 5 miles downwind except for dangerous travel conditions, while the remainder of those within the 10 mile EPZ go inside. Whereas the 2011 version (NRC and FEMA 2011) recommends evacuation or sheltering of the 2 mile radius and 5 miles downwind depending on the nature of the emergency (e.g. rapidly progressing or not) and evacuation conditions (e.g. evacuation time estimates), while the remainder of those within the 10 mile EPZ prepare and monitor for further instructions.

IV.3 Phase 1 – Impact on mortality of protective actions taken upon declaration of a General Emergency

In assessing this phase I assume that a 5 mile radius is evacuated upon declaration of a General Emergency and that the evacuation is effective in preventing significant radiation exposure. I also assume the evacuation results in dislocations lasting long enough to produce excess deaths as observed during the FDNPP accident. This is reasonable considering that the progression of a severe NPP emergency would be very uncertain and off site officials would be reluctant to relax protective actions until they were sure significant releases were not possible, and the impact of any possible releases were fully understood. I also assume that restrictions are placed on ingestion of potentially affected food or water; thus, I do not consider the health effects from ingestion.

[24] The FEMA Program Manual Radiological Emergency Preparedness (FEMA 2015) is the principal source of operational guidance (e.g. check list for exercise evaluation) for FEMAs assessments regarding adherence to 44 CFR Part 350 and NUREG-0654/FEMA-REP-1 and 2 (NRC and FEMA 1980, 2019).

Table 8 shows, according to my estimates[25], that taking protective actions consistent with NRC guidance at this phase may cause about 12 times more excess deaths among the public and about 15 times more excess deaths among elderly residents of care facilities than the excess radiation-induced deaths possibly prevented by these protective actions. These disparities would be much greater if the entire 10 mile plume exposure pathway (EPZ) was evacuated upon declaration of a General Emergency as may be done in some States[26] and as was assumed in the latest analysis of NPP emergencies (NRC 2013a, 2013b). The excess one radiation-induced death per 500 prevented by the protective actions, shown in Table 8, is theoretical, meaning that it would not be discernible even after careful study of many thousands of exposed individuals over their lifetimes, even if it occurs. However, most of the 12 to 15 excess deaths per 500 caused by dislocations resulting from evacuation, shown in Table 8, would be clearly discernible within months to a few years.

Table 8 Excess deaths prevented and caused by protective actions consistent with NRC guidance taken upon declaration of a General Emergency

Protective action	**Excess deaths per 500**	
	(theoretical) due to radiation prevented by evacuation within 5 miles	**(discernible) due to dislocation[b] resulting from evacuation**
Evacuation within 5 mile resulting in dislocation	1[a]	12 among the public 15 among residents of facilities for long stays and the elderly

a. See Table 3.
b. See Table 5.

IV.4 Phase 2 - Impact on mortality of protective actions taken where doses are projected to exceed the EPA PAGs

In assessing this phase I focus on the impact of using the EPA relocation PAG (2 rem/first year) because this will always result in dislocation and associated health effects. I assume that dose projections and environmental monitoring used to identify where the PAG is exceeded are accurate and no areas where the dose is below the PAG are relocated. Table 9 shows my estimate[25] of the excess deaths caused and prevented by relocating people based on the EPA relocation PAG (2 rem first year), as recommended in NRC guidance. This shows that adhering to this NRC guidance and relocating at the EPA PAG may cause 24 times more excess deaths among the public and 30 times more excess deaths among elderly residents of care facilities than the excess radiation-induced deaths (if they occur) prevented by the relocation.

Any protective actions triggered by the PAGs may cause dislocations and associated excess deaths[27]. Table 9 shows that dislocation resulting from application of the EPA PAGs may cause 24 to 600 times more excess deaths among the public and 30 to 750 times more excess deaths among residents of facilities for long stays and the elderly than the excess radiation-induced deaths prevented by the

[25] Excess deaths caused by dislocations resulting from protective actions divided by excess deaths prevented by protective actions that could have resulted from radiation exposure.
[26] Pennsylvania implements a 360-degree, 10-mile evacuation upon declaration of a General Emergency (NRC 2012b, NRC 2013a). Table 3 shows this could result in 60 times more excess deaths among the public and about 75 times more excess deaths among elderly residents of care facilities than the excess radiation-induced deaths possibly prevented by these protective actions.
[27] Dislocations caused either directly due to evacuations or relocations or indirectly due to sheltering or food or water restrictions making areas inhabitable.

protective actions. Dislocation due to water restrictions would be the most dangerous, possibly causing 600 times or more excess deaths among the general public and 750 times or more excess deaths among the residents of facilities for long stays and the elderly than the excess radiation-induced deaths prevented by the restrictions. Furthermore, some States may be using dose criteria lower than EPA PAGs (NRC 2013a) making them potentially more hazardous[28]. These disparities could be even greater when protective actions are taken based on imprecise[29] or conservative dose projections thus resulting in less dose saving than the PAG. The excess radiation-induced cancer deaths prevented by all of the EPA PAGs are theoretical, meaning that they are not discernible even if they occur, whereas many of the excess deaths caused by the dislocations resulting from adherence to the EPA PAGs will be clearly discernible within months to a few years.

EPA stated that one of the principles considered in establishing the PAGs was to *"Balance protection with other important factors and ensure that actions result in more benefit than harm"* (EPA 2017). However, when establishing the PAGs for evacuation and relocation only the health risk during travel was considered and not the much larger health risk due to dislocation (EPA 1992). This principle was not considered at all in establishing the PAG for food and drinking water (EPA 2017). Furthermore, EPA recommends in the calculation of derived response levels (DRL)[30] used to implement the PAGs that conservative assumptions[31] be used in light of the many unknowns involved in an emergency. While this may lower the risk from radiation exposure (assuming the LNT model is correct at low doses), it will also increase the number of people affected by the more likely detrimental health effects caused by the implemented protective actions. During the FDNPP accident the environmental monitoring DRL (i.e. dose rate from deposition) used to identify areas to be relocated was later demonstrated to be about 4 times too low (Miyazaki 2017). This likely resulted in about four times as many people than intended being dislocated based on monitoring[32], along with the resulting detrimental health effects. This demonstrates the importance of using best available data during a response and giving careful consideration before using "*conservative assumptions*" during a response, as such assumptions may cause more harm than good as they could increase the likelihood of the detrimental health impact from protective actions.

[28] The Pennsylvania PAG for relocation is 0.5 rem in the first year (NRC 2013a) which is 4 times lower than the EPA PAG and possibly resulting in about 4 times more excess deaths from dislocation.
[29] Wind shifts and difficulties in making accurate dose projections (e.g. use of inappropriate assumptions) may easily result in protective actions being taken in areas where the doses will not exceed the PAG criteria as seen during the FDNPP emergency.
[30] This is a measurement (e.g. dose rate or food concentration) used directly during an emergency to indicate where or when a PAG is projected to be exceeded.
[31] I assume this means taking actions at projected doses lower than the PAG criteria.
[32] The majority of the dislocations during the FDNPP accident did not occur due to monitoring (Callen and McKenna 2018).

Table 9 Summary of EPA PAG guidelines (EPA 2017) and excess deaths possibly prevented and caused by their implementation

EPA PAG (projected dose) and recommended protective actions	**Excess deaths per 500**	
	(theoretical) due to radiation prevented by protective actions at the PAG[d, e]	**(discernible) due to dislocations caused by the PAG protective actions**[g]
Shelter in place or evacuation [a]		12 among the public 15 among residents of facilities for long stays and the elderly
• 1 rem (10 mSv)/4 days [b,c]	0.2	
Relocation		
• 2 rem (20 mSv) first year[c]	0.5	
• 0.5 rem (5 mSv) following years[c]	0.1	
Food restriction		
• 0.5 rem (5 mSv)/year to the whole body	0.1	
• 5 rem (50 mSv)/year to any organ or tissue	?[f]	
Drinking water restriction		
• 0.1 rem (1 mSv)/year to the whole body of the most sensitive population	0.02	
• 0.5 rem (5 mSv)/year to the general population	0.1	

a. Whichever actions results in the lowest projected dose.
b. The PAG has a range of 1 to 5 rem but I assume 1 rem, the lowest value in the range, will be used by officials to make decisions.
c. Sum of the effective dose from external radiation exposure and the committed effective dose from inhaled radioactive material.
d. Prevented if the protective action is 100% effective but most likely will be lower.
e. Excess radiation-induced cancer deaths projected at the EPA PAG dose based on the LNT model and ICRP fatal radiation risk coefficient. See Table 2.
f. Not assessed here.
g. See Table 5.

IV.5 Limitations of the bases for the findings

The limitations of the bases for the findings of this petition include:

- Reliability of the estimate of the excess early deaths among the public (III.2.4.1 Public (General Population)) (Table 5) resulting from dislocations following the FDNPP accident. This estimate was not supported by analysis of death rates before and after the dislocations (Callen and McKenna 2018). However it is clear there was an increase in the death rate as confirmed by the increase observed during the first month.
- Reliability of the estimates of the excess late deaths following dislocation due to medical conditions (Table 6). These estimates were based on early and limited FDNPP accident data, limited literature review of medical studies and are too recent to be supported by long term studies.
- Reliability of the estimates of the excess late radiation-induced cancer deaths (Table 3 and Table 9). These estimates are based on the LNT model and are for doses below 10 rem (100 mSv) at which excess cancers are not discernible even after careful study of many thousands of exposed individuals over their lifetimes. Projections of radiation induced deaths at such low doses are not

scientifically validated since the level of risk associated with low-dose exposure is unknown (ICRP 2007, UNSCEAR 2011).

- Reliability of estimates of radiation -induced health consequences of General Emergencies based on the latest NRC study of NPP emergencies (NRC 2012a, 2013a, 2013b). The study's shortcomings include: 1) not considering all important early radiation-induced health effects (e.g. to the embryo/fetus), 2) not providing probabilistic risk assessment (PRA) of radiation induced health effects for various protective action strategies as done in earlier studies (e.g. NRC 1990), and 3) not taking into consideration the health impact of protective actions.

While recognizing these uncertainties, the analysis here still supports the need to carefully reexamine the NRC regulations and guidance on protective actions during a General Emergency.

V Application of NRC protective actions guidance

The NRC guidance on protective actions is intended to be used following site-specific modifications (NRC and FEMA 1996, 2011) and after weighing the radiological risk against the risks of the protective action (EPA 2017). Furthermore some States plan to take protective action beyond those recommended by the NRC (e.g. to greater distances or at lower projected doses) possibly in the belief that they provide more protection. The public and public officials could also take protective action beyond those recommended by the NRC during a response "to be sure everyone is safe" (McKenna 2015). However the FDNPP accident and the analysis here demonstrate this may result in excess deaths due to the impact of the protective actions themselves[33].

This shows the importance of providing the public and public officials with guidance to allow them to balance the health hazards of radiation exposure versus the health hazards of protective actions during planning and response, thus allowing them to make truly risk informed decisions (Callen and McKenna 2018). However the NRC does not provide tools to allow decision makers and the public to balance the radiation health hazards versus the health hazards of the protective actions.

VI Problem and proposed solution

VI.1 The Problem

The protective actions taken in accordance with NRC requirements (10 CFR 50.47, Appendix E to Part 50) and implementation guidance (NRC and FEMA 1980, 1996, 2011, 2019) during a General Emergency will likely result in more deaths than would have occurred due to radiation exposure even if no protective actions, other than ingestion restrictions, had been taken. I estimate that dislocations resulting from taking protective actions consistent with NRC guidance (NRC and FEMA 1980, 1996, 2011, 2019) upon declaration of a General Emergency may cause 12 times more excess deaths among the public and 15 times more excess deaths among elderly residents of care facilities than caused by radiation exposure due to the General Emergency. Furthermore dislocations resulting from protective actions taken where EPA PAGs are projected to be exceeded, as called for by NRC guidance, may cause 24 to 600 times more excess deaths among the public and 30 to 750 times more excess deaths among residents of facilities for long stays and the elderly than the excess radiation-induced deaths prevented by the protective actions. The excess deaths caused by protective actions would clearly be discernible within

[33] See sections *"IV.3 Phase 1 – Impact on mortality of protective actions taken upon declaration of a General Emergency"* and *"IV.4 Phase 2 - Impact on mortality of protective actions taken where doses are projected to exceed the EPA PAGs"* for a discussion of the possible adverse health impact the State of Pennsylvania implementing protective actions beyond those recommended in NRC guidance.

months to a year after the accident, while the possible excess radiation-induced deaths prevented by the protective actions, if they occur, would most likely not be discernible even after years of study.

These disparities could be even greater if protective actions are taken beyond those recommended by the NRC (e.g. to greater distances or at lower projected doses) as done by some States[33] possibly in belief that they are more protective. This demonstrates the need for guidance to allow balancing the health hazards of radiation exposure versus the health hazards of protective actions during planning and response and thus to allow truly risk informed decisions to be made. However the NRC does not provide tools to allow decision makers and the public to balance the radiation risk versus the risk of the protective actions during planning and response.

The fundamental problem is that for the last 40 years the objective of emergency response plans has been to provide dose savings (NRC 1978, NRC and FEMA 1980, 2019) and not to do more good than harm. It was assumed for the past 40 years that: 1) protective measures (e.g. evacuations) had limited health risks, which the FDNPP accident demonstrated was wrong, and 2) radiation exposure was hazardous even at very low doses, which is unproven. Furthermore the NRC requirements and guidance are based on analysis, in some cases 40 or more years old, and do not reflect the latest studies of NPP emergencies (NRC 2012a, 2013a, 2013b), which project much smaller releases, and thus smaller radiation-induced health consequences. In other words, NRC requirements and guidance were not established on a truly risk-informed basis.

I recognized that my estimates are uncertain and based on limited analysis and data; nevertheless, they indicate that the NRC regulations and implementation guidance on protective actions during a General Emergency need to be carefully reexamined.

VI.2 Need for rulemaking

To assist the NRC in its evaluation of this petition for rulemaking, 10 CFR 2.802(c)(2) encourages the petitioner to explain why rulemaking is the most favorable approach to address the problem or issue, as opposed to other NRC actions such as licensing, issuance of an order, or referral to another Federal or State agency.

Under Title 10 of the Code of Federal Regulations an operating license for a NPP requires that a *"finding is made by the NRC that there is reasonable assurance that **adequate protective measures can and will be taken** in the event of a radiological emergency"*. However, as shown in this petition, the NRC system of regulations, implementation guidance, analysis, supporting materials and activities (e.g. FEMA regulations and programs[34]) focused on making this finding are clearly inadequate. This is because in the event of a General Emergency protective actions taken in accordance with NRC requirements and implementation guidance would most likely result in protective actions being taken that result in far more deaths than could have resulted from radiation exposure. Obviously protective measures would only be considered adequate if they do more good than harm in terms of public health and safety consistent with the NRC Mission (NRC 2020b).

Therefore the most favorable, and possibly the only effective, approach to address this problem would be rulemaking to ensure ***adequate protective measures*** is interpreted to mean taking protective actions that do more good than harm, considering both the health hazards of radiation exposure and the health hazards

[34] FEMA assessments and ongoing program to insure State and local local, and tribal governments can effectively implement their emergency plans (44 CFR 350.1, FEMA 2015) consistent with NRC requirements (10 CFR 50.47, Appendix E to Part 50) and joint NRC/FEMA guidance (NRC and FEMA 1980, 1996, 2011, 2019)

of protective actions taken to reduce that exposure. This would include an examination of all aspects of the NRC system of regulations, implementation guidance, analysis, supporting materials and activities.

VI.3 Possible solution

Amend NRC requirements (10 CFR 50.47, Appendix E to Part 50), implementation guidance (NRC and FEMA 1980, 1996, 2011, 2019) and supporting analysis, materials and activities, as needed, to ensure that the protective actions taken in the event of a General Emergency will most likely do more good than harm considering the health hazard of both radiation exposure and protective actions[35]. This could include:

- Working with FEMA to establish as one of the objectives of emergency preparedness for NPP emergencies "taking actions that do more good than harm considering both the health hazards of radiation exposure and of protective actions taken to reduce exposure".
- Conducting studies promptly to better quantify the current understanding of health risks of protective actions and associated dislocations.
- Working with FEMA and other stake holders (e.g. public officials) to make needed revisions to NRC requirements, guidance and supporting materials and activities with the objective of taking protective actions in the event of a General Emergency that most likely will do more good than harm. These revisions need to be based on PRA of protective actions strategies considering: 1) updated estimates of important early and late radiation-induced health effects, 2) the detrimental health effects of protective actions and resulting dislocations and 3) possible public response[36]. This needs to consider the application of the EPA PAG's (EPA 2017) which is an integral part of the NRC protective action guidance. This analysis should not be based on conservative assumptions that could distort the results.
- Working with stakeholders to develop guidance for the public and public officials allowing them during planning and response to make truly risk-informed decisions, balancing the hazards of radiation exposure and protective actions and resulting dislocations.

Glossary

EPA Protective Action Guides (PAGs): The projected dose to an individual, resulting from a radiological incident, at which a specified protective action to reduce or avoid that dose is recommended. The EPA PAGs are summarized in Table 9.

General Emergency: A NPP emergency involving *"actual or imminent substantial core degradation or melting with potential for loss of containment integrity or hostile action that result in an actual loss of physical control of the facility"* (NRC 2020a). These are the conditions that could lead to radiation-induced health effects off-site.

Theoretical radiation-induced cancer death: A projected death resulting from a dose for which an increase in the cancer rate would most likely not be discernible even after careful study of many thousands of exposed individuals over their lifetime.

Representative General Emergency: A General Emergency with an offsite risk of radiation-induced cancer deaths (individual latent cancer risk (LCR)) at the high end of those generally projected to occur

[35] A fundamental principle of radiation protection according to the National Council on Radiation Protection and Measurements (NCRP) (Kase 2004) and ICRP (ICRP 2007) is justification. Where justification is assuring *"Any decision that alters the radiation exposure situation should do more good than harm."* (ICRP 2007)

[36] For example unless appropriate public information is provided many members of the public may voluntarily evacuate the entire plume 10 mile EPZ when a General Emergency is declared.

for important NPP core melt emergencies. Here it is based on the Long-Term Station Blackout (LTSBO) scenario (NRC 2013a).

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