March 10, 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 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), guidance and supporting analysis such that: 1) public 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, and 2) the causes of mental health effects resulting from the perceived health effects associated with radiation exposure during a General Emergency are addressed.

Petitioner:

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Attached: 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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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

Petitioner

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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 was one of the authors of the original guidance (NRC and FEMA 1996) on protective actions in the event of a General Emergency. This guidance may still be in use.

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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 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 Nuclear Regulatory Commission (NRC) requirements (10 CFR 50.47, Appendix E to Part 50) and guidance (NRC and FEMA 1996, 2011) during a General Emergency[1] at a nuclear power plant (NPP) will likely result in far more deaths and other severe health effects as a consequence of those actions, than could have resulted from radiation exposure. Furthermore NRC requirements, guidance and supporting analysis do not address limiting the mental health effects expected during a General Emergency. These were the most detrimental health effects of the accidents at Three Mile Island (TMI) and Chernobyl, and were very important during the Fukushima NPP (FDNPP) accident.

This petition for rulemaking, made pursuant to 10 CFR Part 2.802, requests the U.S. Nuclear Regulatory Commission (NRC) to amend as needed its requirements (10 CFR 50.47, Appendix E to Part 50), guidance (NRC and FEMA 1996, 2011) and supporting analysis (e.g. NRC 2013a, 2013b) such that: 1) 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, and 2) the causes of mental health effects resulting from the perceived health effects associated with radiation exposure during a General Emergency are addressed.

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

[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 2020*)*. These are the only conditions that could cause radiation-induced health effects off-site.

comments. First, I provide the basis for my assessment, summarize the problems and review relevant experience from the FDNPP accident. Next, I provide my estimates of the health effects of radiation exposure and protective actions, followed by my estimates of the health effects caused by a response to a General Emergency under NRC requirements and guidance. Finally, I list specific problems and possible solutions regarding NRC analysis, requirements and guidance concerning protection of the public during General Emergencies. I also provide a short glossary of important terms used in this document.

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 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 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' in my analysis of the health effects of both radiation exposure and protective actions. Use of conservative estimates (e.g., assuming the worst effects theorized) can actually result in increased hazards for the public by triggering unwarranted[4] and harmful protective actions. In this connection, I assume for my analysis a "*Representative General Emergency*" [5] that has offsite radiation-induced death risks representative of those for the important NPP emergencies (core damage scenarios) (NRC 2012, 2013a, 2013b) and not the accident scenarios with the greatest risks which are far less likely.

I.3 Summary of the problems

The first problem is that the FDNPP accident experience (e.g., Hasegawa 2016, IAEA 2015a, NAIIC 2012 Tanigawa 2012) and subsequent early analysis (e.g., Callen and McKenna 2014) 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 1996, 2011) during a General Emergency could result in far more deaths and other severe health effects than from radiation exposure. Therefore, one of the fundamental tenets of this petition is that the response during a General Emergency should be justified, meaning that it should do more good than harm. The protective actions taken should not result in more health effects than the radiation related health effects 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 deaths among the public and 15 times more deaths among elderly residents of care facilities than caused by the resulting radiation exposure during a representative General Emergency[6]. The disparity could be even greater when protective actions are taken based on EPA Protective Actions Guides (PAGs)[7], 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

[2] Relative risk is the ratio of health effect rates of two differently affected groups (e.g. exposed and not exposed).
[3] For example, there were about 15 excess deaths per 500 elderly residents dislocated from care facilities during the FDNPP accident.
[4] In terms of the health risk from radiation exposure.
[5] See Glossary.
[6] See section *'IV.3 Phase 1 – Impact on mortality of protective actions taken upon declaration of a General Emergency'*
[7] 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'*

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 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.

The second problem is that NRC requirements, guidance and supporting analysis do not address limiting the causes of the mental health effects (e.g. post-traumatic stress disorder (PTSD)) expected during a General Emergency. These were the most detrimental health effects of the TMI, Chernobyl, and possibly the FDNPP accidents. These mental health effects were associated with fear and uncertainty concerning radiation health effects caused by wrong, conflicting, confusing, and so-called conservative assessments from officials, experts and the media. Therefore, another tenet of this petition is that actions should be taken in the event of a General Emergency to put the health hazards from ionizing radiation in perspective, such that it is understandable for the public and public officials.

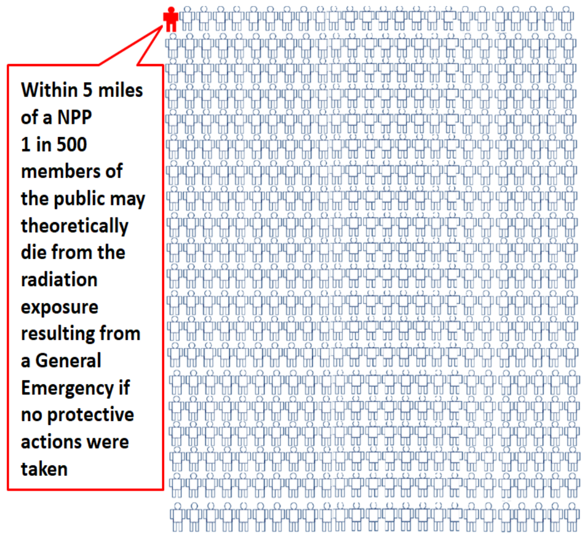

Figure 1 Deaths per 500 people within 5 mile of a NPP caused by radiation exposure resulting from a representative General Emergency if no protective actions were taken.

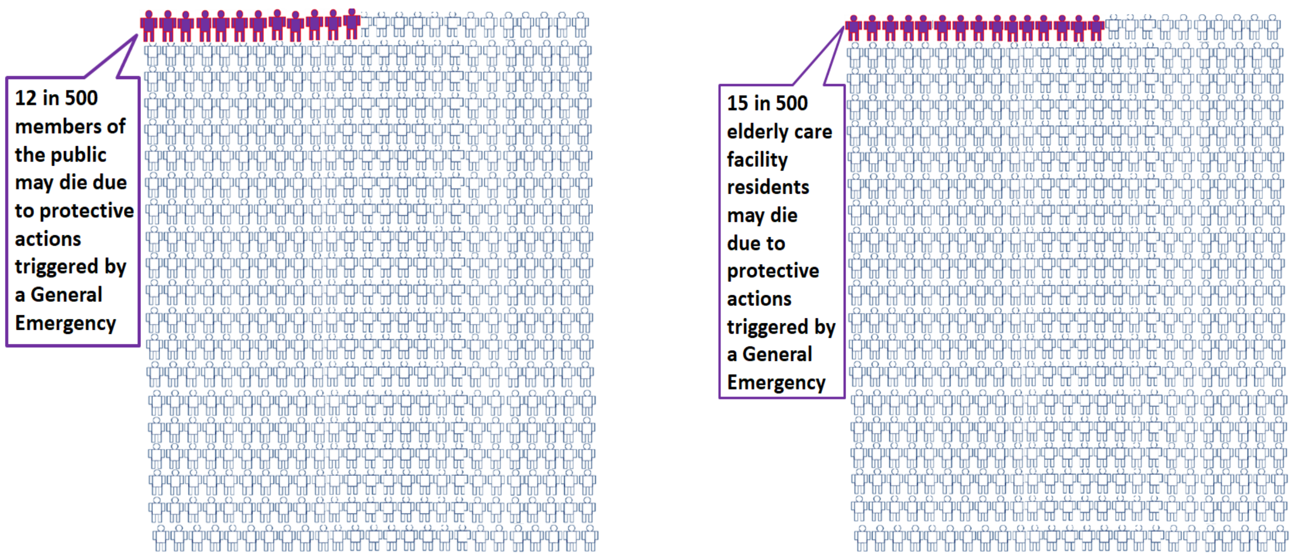

Figure 2 Deaths per 500 (public and elderly care facility residents) within 5 miles caused by protective actions triggered by declaration of a General Emergency in accordance with NRC guidance.

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 and 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 2014, 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[8] (Fukushima Prefectural Government 2019) caused principally by evacuation and sheltering[9], resulted in hundreds of deaths, adverse health conditions (e.g. hypertension), mental health concerns (e.g. post-traumatic stress disorder (PTSD)), social issues (e.g. stigma), 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 recommended 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. Use of NRC guidance during an NPP General Emergency could result in deaths and other adverse health effects caused by protective actions even though there would be no discernible radiation-induced deaths among the public. Consequently, the most likely cause of adverse health effects during a General Emergency would not be radiation exposure but protective actions taken in accordance with NRC requirements and guidance and/ or from the perceived health effects of radiation exposure.

Numerous authors, following the FDNPP accident, have emphasized that the health effects of protective actions (e.g. evacuations) and effects of concerns about radiation exposure on mental health 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. In the case of any radiation exposure, the serious fear and stigma can lead to highly detrimental mental and social suffering.*" (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, depression, lack of purpose and the insidious fear of a death sentence from radiation exposure. Psychologically we were wrecked, I'm still taking pills for high blood pressure*" (Harding 2018).

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

[9] During the FDNPP emergency people evacuated (dislocated) from areas where sheltering was advised for several reasons: 1) 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).

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[10] (NRC 1978). Early radiation-induced health effects typically occur due to high doses received over days or less and typically are seen within months of exposure. The early radiation-induced effects that may be important (IAEA 2005) during a General Emergency are shown in Table 1. However, the latest NRC analysis (NRC 2012, 2013a, 2013b) did not appear[11] 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.

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**
200 – 300 rem (2 - 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.
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 an NPP release (for a light water reactor) (EPA 1988, 1993, ICRP 2002).
c. Keeping the dose below this dose should prevent other important non-fatal early effects.
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[12] 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

[10] Early radiation-induced effects are also called deterministic effects, acute effects, prompt effects, and tissue reactions.
[11] The only estimates of early 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 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).
[12] Late radiation-induced health effects are also called stochastic effects, latent effects, and delayed effects.

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 fatal radiation-induced cancers, as is typically done, using the linear-non-threshold (LNT) model[13.] This model assumes the risk of 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). The assumption of excess risk at low doses is controversial and not universally accepted nor scientifically validated since the level of risk associated with low-dose exposure is unknown (ICRP 2007). Thus I refer to radiation-induced cancer deaths projected by the LNT 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 for the representative General Emergency 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 radiation-induced cancers 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.

[13] Assuming a lifetime risk of fatal cancer (fatal radiation risk coefficient) of 5 % (ICRP 2007) at 100 rem (1 Sv) or 25 deaths per 500 members of the public.

Table 2 Approximate late radiation-induced cancer deaths deaths per 500 members of the public due to radiation (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) (ICRP 2007) at 100 rem (1 Sv).

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 US cancer death rate of about 25% (125 lifetime deaths per 500) (ACS 2019).

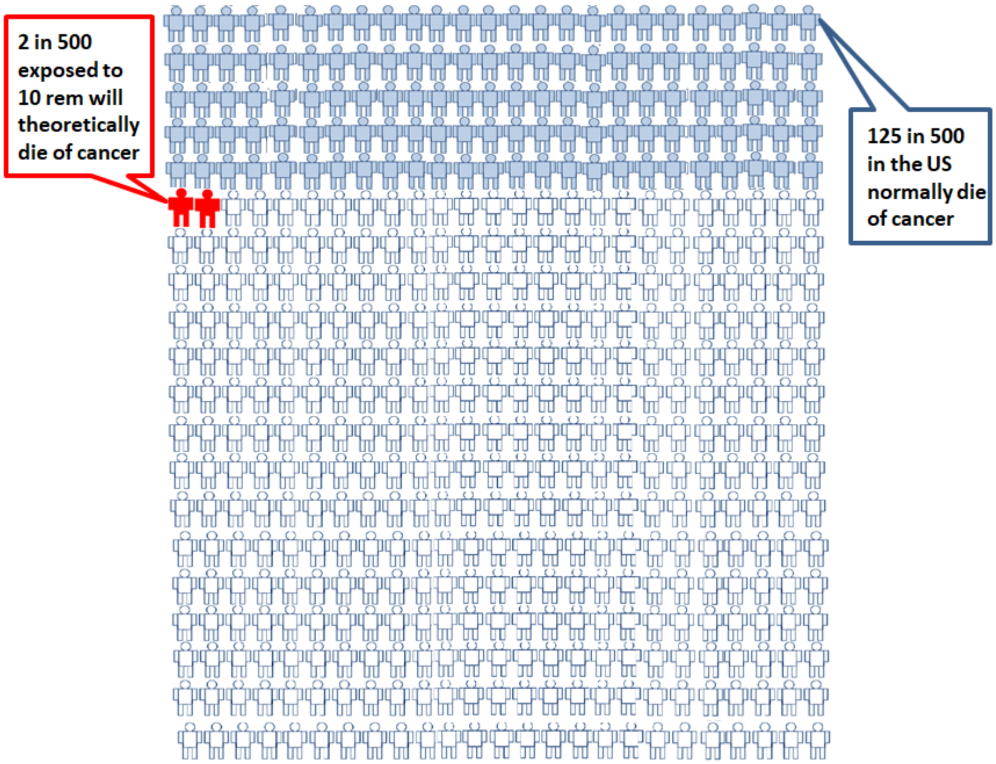

Figure 3 Late (theoretical) deaths per 500 members of the public exposure to 10 rem (100 mSv) based on the LNT model and those in the US who normally die from cancer.

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 protective actions (e.g. evacuation or sheltering) are taken other than ingestion restrictions. My estimates were based on the latest NRC studies of NPP accidents (NRC 2012, 2013a, 2013b). I estimate that the representative General Emergency will cause about one theoretical 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 or sheltering 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)[b]
10 mile radius	0.1 (theoretical)[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 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 (D) stability class (NRC 1978).
b. Considered theoretical because they would not be discernible even if they occurred.

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 and mental health effects associated with the public's perception of the health effects of radiation exposure

III.1 Introduction

Two important health effects not related to radiation exposure during a General Emergency are: 1) the physical health effects (e.g. deaths) due to protective actions, and 2) the mental health effects associated with the public's perception of the health effects of radiation exposure.

III.2 Physical health effects due to protective actions

III.2.1 Introduction

The protective measures called for in NRC guidance (NRC and FEMA 1996, 2011) 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.2.2 Shelter and preparation to evacuate

Sheltering and instructions to prepare to evacuate within an area could cause deaths and other health effects if they result in dislocations[14] 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).

III.2.3 Travel (movement) during evacuation and relocation

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

The unsupported 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 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 [15] 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 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).

[14] During the FDNPP emergency people evacuated (dislocated) from areas where sheltering was advised for several reasons: 1) 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).

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

III.2.4 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.2.4.1 Public (General Population).
b. See section III.2.4.2 Residents of facilities for the elderly and long stay residents.

III.2.4.1 Public (General Population)

The 7 excess early deaths per 500 dislocated (1.4 %) shown in Table 5 are based on the 2000 disaster related deaths (DRD)[16] among the 147,000 dislocated from Fukushima Prefectures due to the FDNPP accident[17] as of 30 September 2019 (Reconstruction Agency Japan 2019, Saji 2013, Hasegawa 2016, Hayakawa 2016). These dislocations were primarily due to FDNPP accident evacuation and sheltering[14] 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 it is clear there was an increase in the death rate due to dislocation, as observed by the large increase during the first month after the accident.

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 very uncertain being based on early data, limited literature review of medical studies and not confirmed by long- term studies.

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[16] 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).

[17] 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.

Table 6 Medical conditions, excess prevalence after dislocation, and estimated resulting late deaths during and after the FDNPP accident.

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]	3
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[18] 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.

III.2.4.2 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 evacuations.

III.2.5 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.

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

III.3 Mental health effects associated with the public's perceptions of the health effects of radiation exposure

III.3.1 Introduction

Mental health effects are often cited as the most detrimental health consequence of severe NPP emergencies and include depression, anxiety, stigma, and post-traumatic stress disorder (PTSD). These effects are often associated with confusion and uncertainty about radiation-induced health effects (Bromet 2014, ICRP 2012, Maeda 2017, 2018, WHO 2013). This confusion and uncertainty is often due to conflicting and confusing assessments by officials, experts and the media, compounded by the misuse of units and concepts intended for use during normal operation (ICRP 2012).

III.3.2 Mental health effects of TMI and Chernobyl emergencies

The President's Commission on the TMI accident (Kemeny 1979) concluded that the major health effect of the accident was on mental health, even though the population had received very low doses. The World Health Organization (WHO) concluded that the largest public health problem caused by the Chernobyl accident (WHO 2006) was related to mental health. The major risk factor associated with these mental health effects was the public's perceived risk of radiation-induced health effects (Bromet 2012, ICRP 2012). The international forum on Chernobyl's health, environmental and socio-economic impacts (IAEA 2006) found the public had "*an exaggerated sense of the dangers to health of exposure to radiation"* and exhibited anxiety, confusion and uncertainty about the impact of radiation on their health and this showed no sign of diminishing 30 years after the accident.

III.3.3 Mental health effects of the Fukushima accident

Mental health effects are one of the most serious health effects of the FDNPP accident and include post-traumatic stress disorder (PTSD), stigma, stress, depression, chronic anxiety and guilt (Hasegawa 2016, ICRP 2012, WHO 2013). The United Nations Scientific Committee on the Effects of Atomic (UNSCEAR) concluded concerning the FDNPP accident that *"No discernible increased incidence of radiation-related health effects are expected among exposed members of the public or their descendants. The most important health effect is on mental and social well-being, related to the enormous impact of the earthquake, tsunami and nuclear accident, and the fear and stigma related to the perceived risk of exposure to ionizing radiation. Effects such as depression and post-traumatic stress symptoms have already been reported"* (UNSCEAR 2014). Table 7 shows some of the excess mental health conditions among evacuees identified by studies of the FDNPP accident. About 50 per 500 (10%) evacuees suffered depression (Maeda 2017) and 100 to 250 per 500 (20 to 50%) possibly suffered from PTSD (Yabe 2014, Tsujiuchi 2016). Stigma and prejudice toward those who may have been in the contaminated areas resulted in discrimination, anger, loss of self-esteem, bullying of children, and was still occurring 6 years after the accident (Hasegawa 2016, ICRP 2012, NAIIC 2012, Sawano 2018).

Table 7 Example of some excess mental health effects associated with the FDNPP accident

Mental health effect	Excess among evacuees per 500
Depression and other mental health problems	50
PTSD	100 to 250
Stigma	?

Mental health effects during the FDNPP accident are often associated with fear of the possible health effects of radiation exposure (Bromet 2012, Hasegawa 2016, ICRP 2012, Maeda 2017, Miura 2017,

Suzuki 2015, Yabe 2014) even though no discernible increased radiation-induced health effects were projected (UNSCEAR 2014). In 2012 about 25 % (Suzuki 2015) of the people from the evacuation zones believed that radiation-induced health effects were very likely and in 2017 about 70 % of those evacuated from the town of Tomioka believed that radiation-induced health effects would occur if they returned to live in the town (Matsunaga 2018**)**. When the Japanese government lifted the evacuation order for Tomioka on 1 April 2017, 70% of the evacuees said they did not intend to return because of anxiety about the potential health effects of radiation exposure (Matsunaga 2018**)**.

Misconceptions concerning radiation risks are in part due to the exaggerated, contradictory, and incomprehensible assessments of health impacts of radiation exposure made by government representatives, medical professionals, academics and numerous others viewed as experts by the media and public (ICRP 2012, McKenna 2014). This is not surprising; since there is no consensus, even among experts (e.g. the health physics community), of the health effects of radiation exposure during NPP emergencies. The common understanding of radiation health effects is based on concepts intended for normal operations where it is *conservatively* assumed there is no safe dose. This may be an appropriate assumption during normal operations, but not during emergencies when actions taken to reduce radiological exposure may have severe consequences (e.g. deaths). During an emergency those making protective action decisions (e.g. public and public officials) need information allowing them to balance the hazards of radiation exposure versus the hazards of actions taken to reduce exposure. However, the NRC does not provide such information, and the guidance that is provided may actually do more harm than good. For example the EPA PAG guidance (EPA 2017) states that protective actions are justified, implying they do more good than harm, when such protective actions will most likely cause more harm than the radiation prevented[19]. What is needed is guidance allowing the public and public officials to balance the hazards of radiation exposure versus the hazards of protective actions (Callen and McKenna 2018).

Furthermore, radiation protection concepts intended for normal operations were found not to be suitable for communicating with the public during the FDNPP accident (ICRP 2012). One common example expected during any emergency is exaggerated estimates of radiation-induced deaths (e.g. 500,000 deaths for the FDNPP accident) even though individual doses are very low. These estimates are based on the LNT model (ICRP 2012) and collective dose even, though ICRP says this is inappropriate (ICRP 2007, 2012). Dose limits are another example. Before the FDNPP accident the "limit" for public radiation exposure was 0.1 rem (1 mSv) per year and after the accident it was 20 times higher. Thus the public thought they were not being protected believing a dose above 1 mSv was not safe (ICRP 2012). The same problem could occur in the U.S., since the NRC dose limit for the general public during normal operations (HPS 2020) is much lower than the EPA PAGs dose criteria for taking protective actions (EPA 2017). What is needed is guidance that addresses common errors expected during emergencies (e.g. projecting deaths from very low doses) that may cause harmful misconceptions concerning radiation-induced health effects (IAEA 2013).

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*

[19] See section '*IV.4 Phase 2 - Impact on mortality of protective actions taken where doses are projected to exceed the EPA PAGs'*

measures can and will be taken in the event of a radiological emergency". Such a finding requires 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)[20] upon declaration of a General Emergency. The federal guidance on acceptability of emergency plans is principally contained in NUREG 0654 Rev. 1 (NRC and FEMA 1980) published in 1980 which states that "*The overall objective of emergency response plans is to provide dose savings (and in some cases immediate lifesaving) for a spectrum of accidents that could produce offsite doses in excess of 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). 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[21] (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).

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 2012, 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 8: 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).

[20] 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.

[21] 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).

Table 8 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 food and water restrictions as shown in Table 10.

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 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 result in excess deaths and other health effects, 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.

Table 9 shows, according to my estimates[22], that taking protective actions consistent with NRC guidance at this phase may cause about 12 times more deaths among the public and about 15 times more deaths among elderly residents of care facilities than the 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, as was assumed in the latest analysis of NPP emergencies (NRC 2013a, 2013b). The one radiation-induced death per 500 prevented by the protective actions, shown in Table 9, 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 deaths per 500 caused by dislocations resulting from evacuation, shown in Table 9, would be clearly discernible within months to a few years.

[22] Deaths caused by dislocations resulting from protective actions divided by deaths prevented by protective actions that could have resulted from radiation exposure.

Table 9 Deaths prevented and caused by protective actions consistent with NRC guidance taken upon declaration of a General Emergency

Protective action	**Deaths per 500**	
	(theoretical) due to exposure 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 10 shows my estimate [22] of the excess deaths caused by 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 may cause 24 times more deaths among the public and 30 times more deaths among elderly residents of care facilities than the radiation-induced deaths (if they occur) prevented by these protective actions.

Any protective actions triggered by the PAGs may cause dislocations and associated deaths[23]. Table 10 shows that dislocation resulting from application of the EPA PAGs may cause 24 to 600 times more deaths among the public and 30 to 750 times more deaths among residents of facilities for long stays and the elderly than the radiation-induced deaths prevented by the 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 radiation-induced deaths prevented by the restrictions. Furthermore, some States may be using dose criteria lower than EPA PAGs[24] (NRC 2013a) making them potentially more hazardous. These disparities could be even greater when protective actions are taken based on imprecise[25] or conservative dose projections thus resulting in less dose saving than the PAG. The 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 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

[23] Dislocations caused either directly due to evacuations or relocations, or indirectly due to sheltering or food or water restrictions making areas inhabitable.
[24] The Pennsylvania PAG for relocation is 0.5 rem in the first year (NRC 2013a) which is 4 times lower than the EPA PAG.
[25] 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.

considered and not the much larger 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)[26] used to implement the PAGs that conservative assumptions[27] 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 being dislocated based on monitoring[28], 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.

Table 10 Summary of EPA PAG guidelines (EPA 2017) and deaths possibly prevented and caused by their implementation

EPA PAG (projected dose) and recommended protective actions	**Deaths per 500**	
	(theoretical) radiation deaths 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. Radiation-induced cancer deaths projected for 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.

[26] 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.
[27] I assume this means taking actions at projected doses lower than the PAG criteria.
[28] The majority of the dislocations during the FDNPP accident did not occur due to monitoring (Callen and McKenna 2018).

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 due to dislocation as 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 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 10). 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 2012, 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 only 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). However the NRC does not provide tools to allow decision makers and the public to adapt the guidance during planning or response in a way to balance the radiation risk versus the risk of the protective actions. Thus, as discussed earlier, the public and public officials need guidance to allow them to balance the hazards of radiation exposure versus the hazards of protective actions (Callen and McKenna 2018).

VI Specific problems and proposed solutions

Problem 1: The protective actions taken in accordance with NRC requirements (10 CFR 50.47, Appendix E to Part 50) and guidance (NRC and FEMA 1996, 2011) during a General Emergency will likely result in far more deaths and other severe health effects 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 1996, 2011) upon declaration of a General Emergency may cause 12 times or more excess deaths among the public and 15 times or more excess deaths among elderly residents of care facilities than could be caused by radiation exposure[29]. 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 or more excess deaths among the public and 30 to 750 times more deaths among residents of facilities for long stays and the elderly than the radiation-induced deaths prevented by the protective actions. The excess deaths caused by protective actions would clearly be discernible within 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. The disparity could be even greater if protective actions are taken based on imprecise or conservative dose projections[30] or criteria lower than the EPA PAGs as may be done by some States. I recognized that my estimates are uncertain and based on 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.

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) 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 2012, 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.

Problem 1 solution: Revise NRC requirements (10 CFR 50.47, Appendix E to Part 50) and guidance (NRC and FEMA 1996, 2011), as appropriate, 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. This could include:

- Establishing as one of the objectives of emergency plans 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.
- Making needed revisions to NRC requirements and guidance with the objective of taking protective actions during NPP emergencies that most likely will do more good than harm in the event of a General Emergency. These revisions need to be based on PRA of protective actions strategies considering:1) the latest 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

[29] Assuming actions are taken to prevent ingestion of food and water that could cause a detectible increase in thyroid cancers.
[30] Resulting in taking protective actions where the established criteria have not actually been exceeded.

response[31]. 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 (e.g. public officials) 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.

Problem 2: For the past 40 years, starting with the TMI accident, mental health effects have been found to be possibly the most detrimental health effect from NPP emergencies. These mental health effects are often associated with fear and uncertainty about the health effects of radiation exposure caused by conflicting and scientifically unsupported assessments and confusion caused by the use of concepts intended for normal operations. However, neither NRC requirements nor guidance include provisions to counter these causes of mental health effects during a General Emergency.

Problem 2 Solution: Revise the NRC requirements (10 CFR 50.47, Appendix E to Part 50) and guidance (NRC and FEMA 1996, 2011), as appropriate, to reduce the causes of mental health effects in the event of a General Emergency This could include:

- Establishing as one of the objectives of emergency plans for NPP emergencies "making provisions to reduce the causes of mental health effects".
- Revise NRC requirements and guidance to reduce the causes of mental health effects during General Emergencies. These revisions need to be based on analysis of the contributors to mental health effects as experienced in past NPP emergencies.
- Working with stakeholders (e.g. public officials) to develop guidance for use during planning and response for General Emergencies on the reduction of the causes of mental health effects, to include placing the health effects of radiation and protective actions into perspective and addressing concerns observed in past emergencies.

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 10.

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 2020). 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 for important NPP core melt emergencies. Here it is based on the Long-Term Station Blackout (LTSBO) scenario (NRC 2013a).

[31] 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.

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