



**Pacific  
Northwest**  
NATIONAL LABORATORY

# Scoping Study to Demonstrate Viability of Risk-Informed Approach for Approval of a Transportation Package for a Transportable Nuclear Power Plant for Maritime Shipment

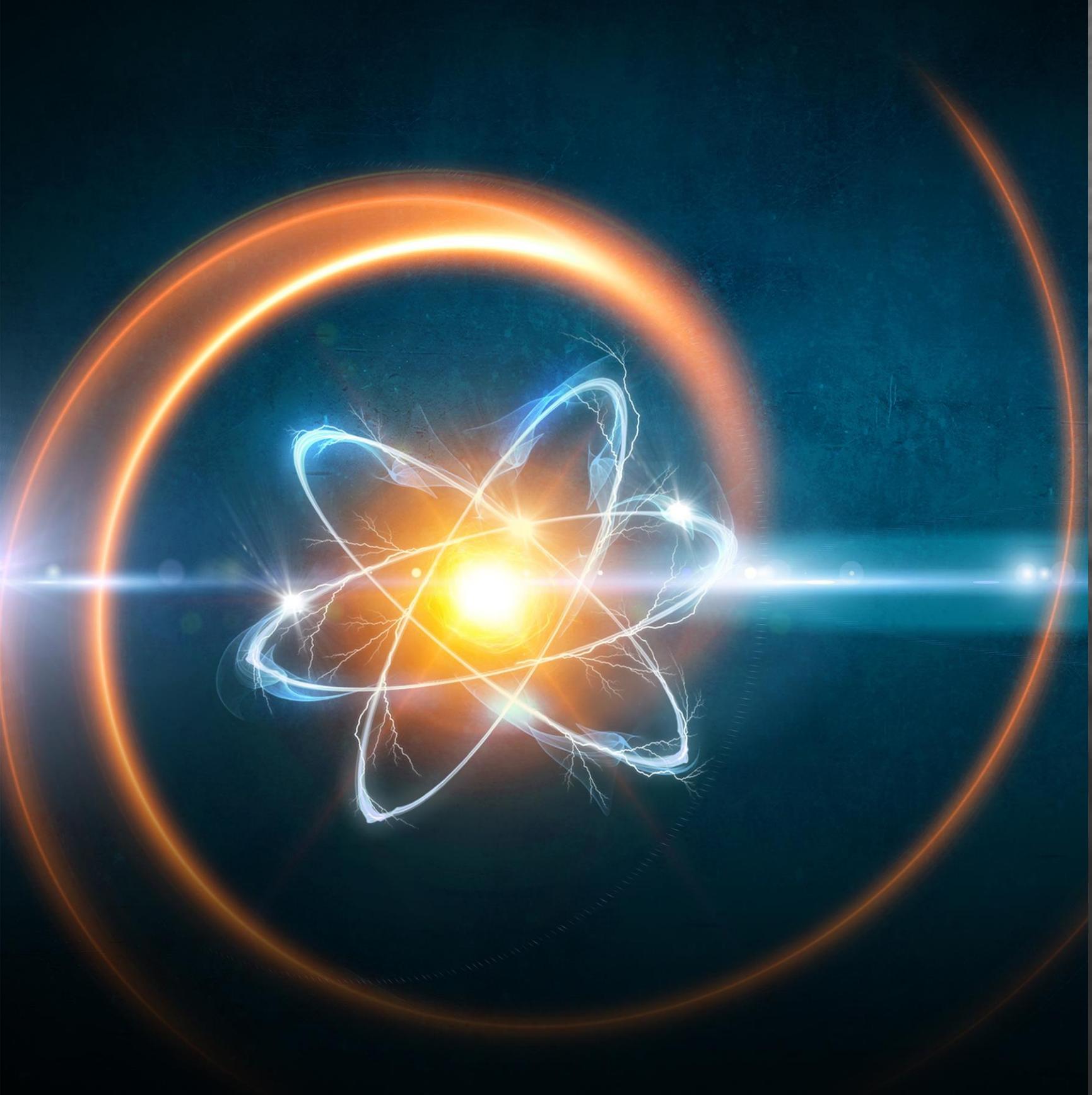
**DISTRIBUTION STATEMENT A:**  
Approved for Public Release.  
Distribution is unlimited.

**Harold Adkins  
Garill Coles  
Steve Short  
Steve Maheras  
Pete Lowry**

Nuclear Regulatory Commission  
Pre-engagement Meeting  
March 5, 2025

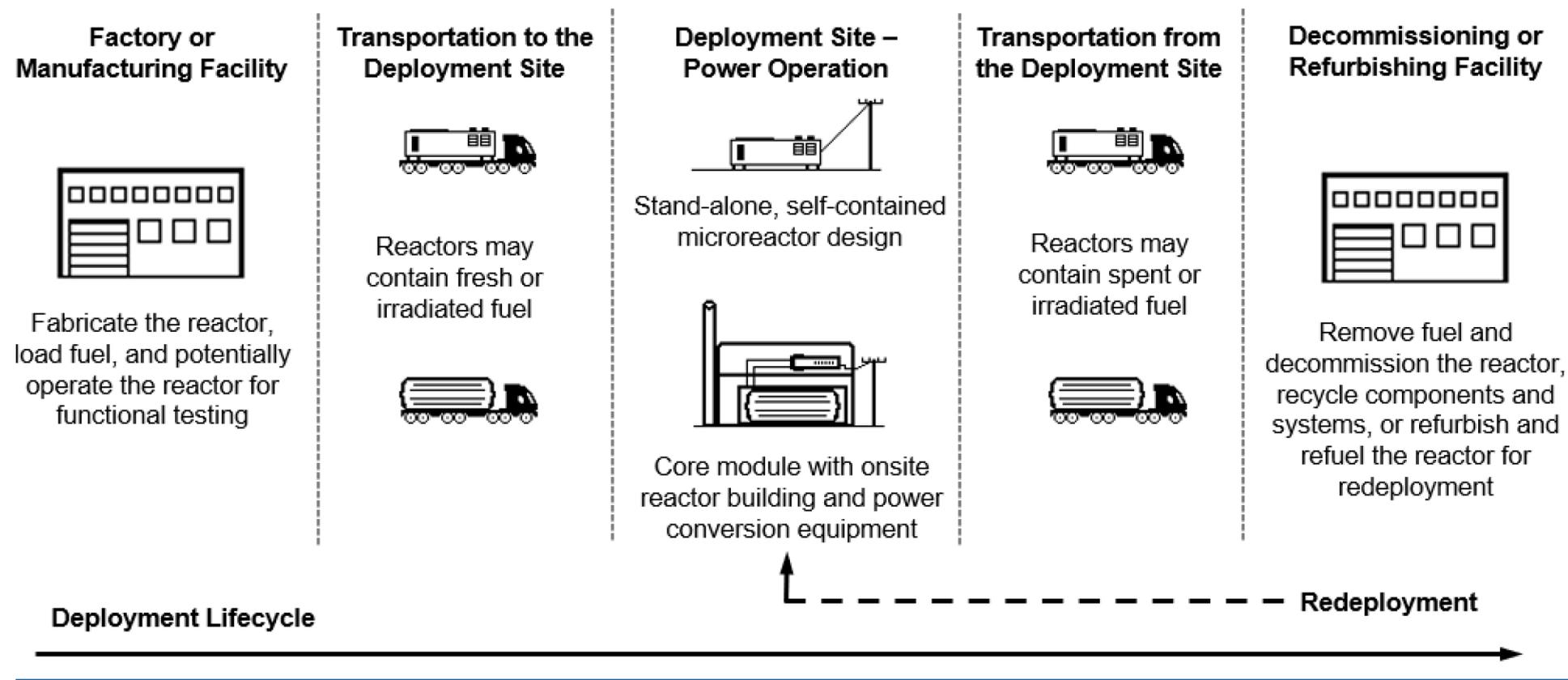
U.S. DEPARTMENT OF  
**ENERGY** **BATTELLE**

PNNL is operated by Battelle for the U.S. Department of Energy



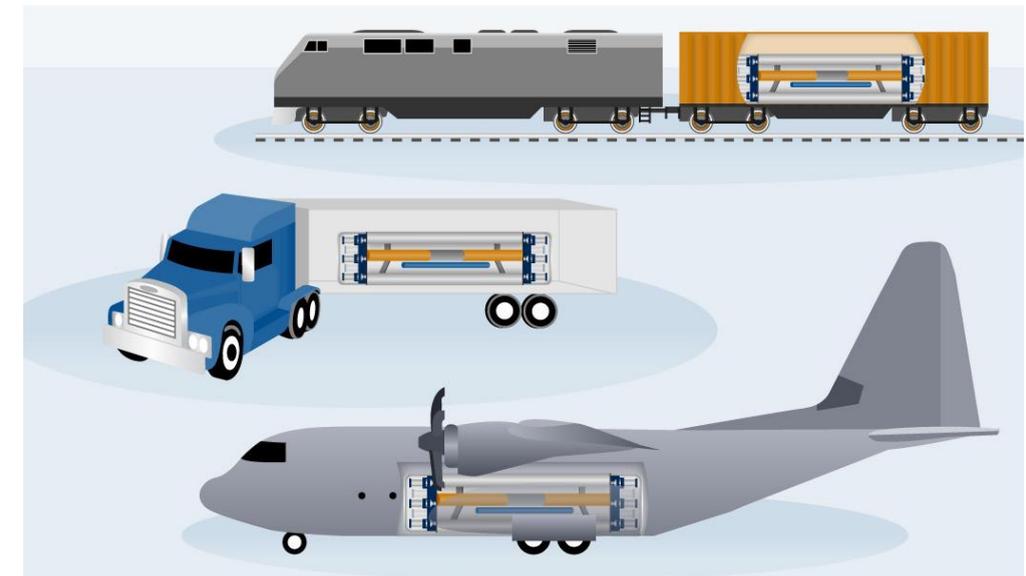
# General Introduction

- Microreactors are currently being designed to be factory fabricated and fueled, transported to desired sites to be operated, and then returned to the factory
- As such they may be transported with its unirradiated or irradiated fuel as shown in the graphic taken from an NRC presentation dated Feb 20, 2025



# General Introduction

- A microreactor package with its unirradiated or irradiated contents may not meet the entire suite of NRC regulatory requirements in 10 CFR Part 71
- A risk-informed process can be used for NRC transportation package approval
  - To demonstrate equivalent safety and that risk to the public is low
  - This will likely require the use of compensatory measures
- The presentation that follows is about a study performed to demonstrate the viability of a risk-informed approach for transportation package approval for a Transportable Nuclear Power Plant (TNPP) for maritime shipment and more specifically the PNNL draft report that documents that effort.



Source: GAO. | GAO-20-380SP

# Outline of the Presentation

- Purpose and scope of the study presented in this meeting
- International agreements associated with maritime shipment of plutonium
- The risk-informed regulatory approach and proposed risk evaluation guidelines
- Description of what's in the report
  - A description of the general transportation Probabilistic Risk Assessment (PRA) methodology
  - A demonstration PRA based on an assumed Transportable Nuclear Power Plant (TNPP) design concept, the assumed transport vessel, and an assumed route
  - Identification of the major elements of the PRA and how they were performed
  - Discussion of the PRA results and insights
  - Discussion of appendices that present data and supporting analyses
- Final thoughts about the proposed approach and demonstration

## Purpose of Study

- Previous work demonstrates the viability of a risk-informed regulatory approach developed by PNNL for **domestic highway** transport of the DOD project Pele TNPP
  - Performed for the Strategic Capabilities Office (SCO) documented in **PNNL-36380, Rev 1**
- NRC found implementation of the approach developed for DOD project to be an acceptable way to seek TNPP transportation package approval after review of PNNL-36380 and interaction with PNNL staff including a round of RAIs
- NRC **officially endorsed** the approach October 2024 in a letter to SCO which refers to a previously issued **NRC Methodology Evaluation** attached to a letter to SCO dated August 5, 2024.
- However, the transportation of a TNPP could, in many possible uses, **require multiple modes of transport** (e.g., highway, maritime, rail and barge).
- The evaluation reported here takes demonstration of the risk-informed regulatory approach a step further by applying it to **maritime transport** of a TNPP package.

## Scope of Study

- This demonstration of the risk-informed approach for maritime transportation is considered a scoping study because it is not as comprehensive as the domestic highway study in the following ways:
  - The PRA is limited to selected accidents that **dominate the risk** of maritime shipment of a TNPP package based on historical risk studies of the maritime shipment of certified packages carrying irradiated material and Pu.
    - In contrast to using a comprehensive accident identification and development process for a TNPP package that is not expected to meet applicable federal deterministic requirements.
  - Also, the study is based on a **notional design concept** that borrows from multiple microreactor design sources, given the limitations in availability for a detailed design.
- The notional TNPP design concept for this study is meant to be of sufficient size to increase electrical **power reliability** at a military base but **small enough** to be transported by ground and shipped to the desired location.
  - Assumed to be a **TRISO** fueled **High Temperature Gas** (HTG) rated at **20 MWth**
  - Modular in design (**e.g., CONEX-box like structures**) with nearly all radioactive material contained in the Reactor module. So, like the design evaluated in the domestic highway study.

## Scope of Study

- The assumed route for the study is from a U.S. port to a U.S. port (i.e., **Military Ocean Terminal Concord California to Naval Base Guam**) but goes through international waters. However, a route could go through territorial waters and/or to a foreign port.
- It is assumed that TNPP Package is transported using an Irradiated Nuclear Fuel (INF) ship at the appropriate class (e.g., **Class 2 or 3**) to meet international agreements which have commensurate safety features and systems.
  - The U.S. follows the **INF code** introduced by the International Maritime Organization (IMO) specifically for shipping irradiated fuel, plutonium, and high-level radioactive waste.
  - Using the code INF vessels are **certified as Class 1, 2 or 3 based on the aggregate radioactivity** of material they can carry
  - A Class 3 INF vessel has no upper limit on the aggregate radioactivity
  - Other differences between INF 3 ships versus and INF 1 and 2 ships include more safety system capability such as enhanced fire protection and extra electrical supply systems

# International Agreements and the INF Code

- The Safety of Life at Sea (**SOLAS**) convention is one of the most important international agreements regarding merchant ship safety. It provides:
  - Standards for ship construction, equipment, and operation (e.g., fire protection, emergency preparedness)
  - And the requirement to comply with the International Maritime Dangerous Goods (IMDG) Code
- The **International Maritime Organization** (IMO) is the global standard-setting authority for the safety, security and environmental performance of international shipping
  - IMO an agency of the United Nations
- The **IMO developed the IMDG Code** as an international code for the maritime transport of dangerous goods
  - IMDG Code lays out regulatory framework for handling dangerous goods and marine pollutants
  - IMDG Code is harmonized with IAEA Specific Safety Requirements No. SSR-6, Regulations for the Safe Transport of Radioactive Material
- One of the supplements to the IMDG Code is the **INF Code** – International Code for the Safe Carriage of Packaged **Irradiated Nuclear Fuel**, Plutonium and High-Level Radioactive Waste on Board Ships
  - INF Code was introduced in 1993 and became mandatory in January 2001

# Safety Systems of an INF Class 3 Ship



# Risk-informed Regulatory Approach

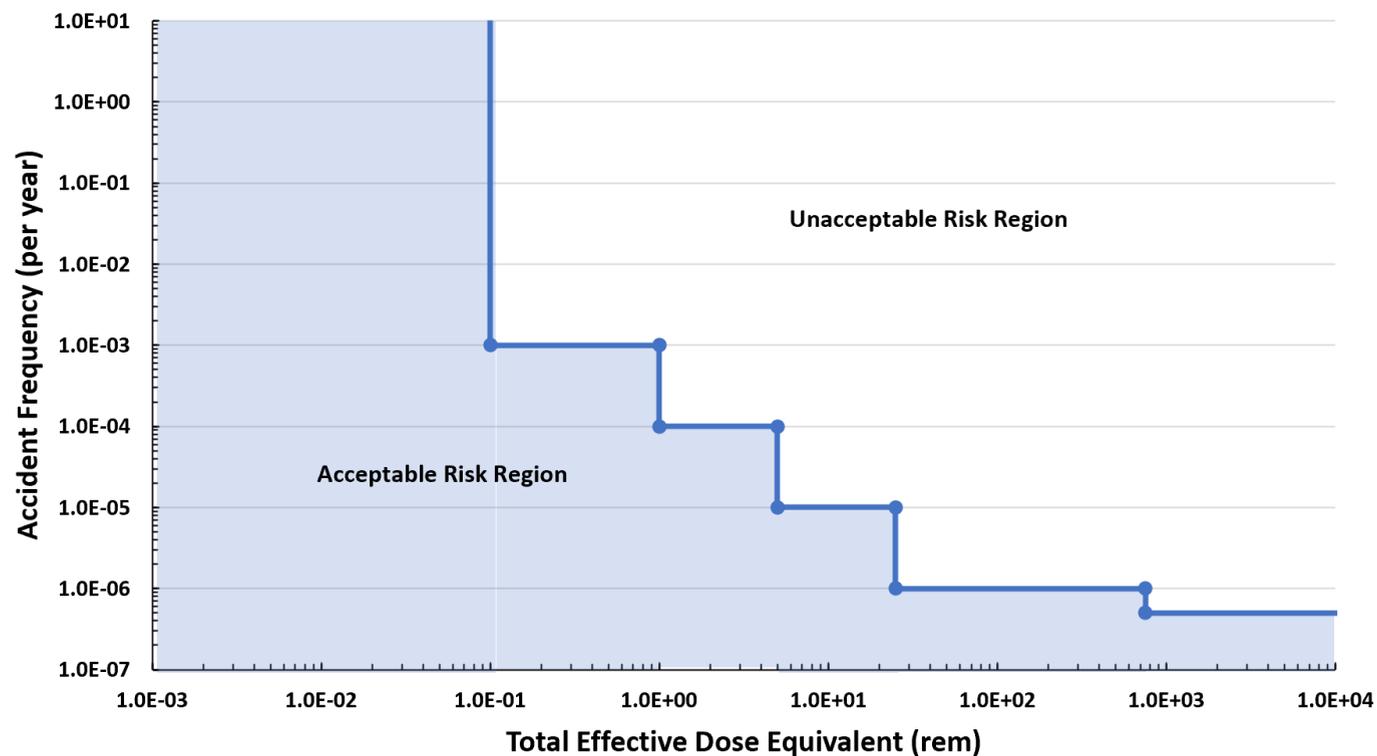
The **three elements** of the risk-informed regulatory approach developed for domestic highway transportation primarily using U.S. nuclear regulations and example applications. For this study, these elements were reexamined in the light of applicable international nuclear regulations and applications.

- 1) The U.S. 10 CFR 71.12 “**Specific exemption**” approach which can be used with quantitative risk information which NRC has allowed. This is done because it is expected that it will be difficult for the TNPP package to meet the federal deterministic requirements for a radioactive material package given the complexity of its physical shape and other features compared to a transportation cask.
  - The IAEA SSR-6 (IAEA 2018) “**Special arrangement**” process can be used in similar way as the U.S. specific exemption process with sufficient basis.
- 2) Use of **PRA to quantify the risk**.
  - PRA modeling is mature practice throughout the world and is used and accepted internationally for risk informed decision making using quantitative risk information
- 3) **Risk evaluation guidelines** that define acceptable levels of risk
  - International use of risk matrix using similar values accepted for nuclear applications
  - International use of limits/goals expressed as PRA metrics in nuclear regulations are largely consistent with those derived from PRA established in U.S. nuclear regulations.

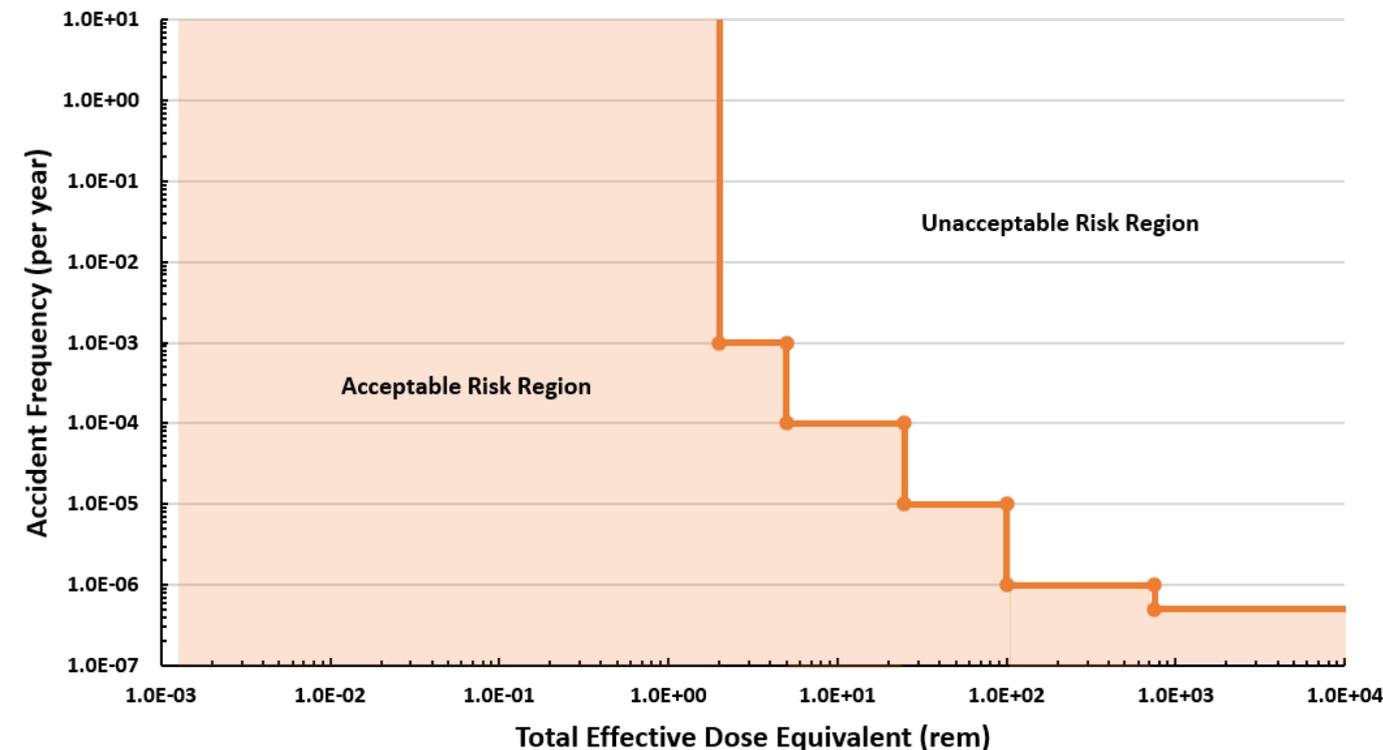
# Proposed Risk Evaluation Guidelines

The proposed risk evaluation guidelines are the same as for domestic highway and compatible with the U.S. Safety Goal Policy Statement and NRC-proposed QHGs in the (NRC 2008) report, "Risk-Informed Decisionmaking for Nuclear Material and Waste Applications."

For the Maximum Exposed Member of the Public



For the Worker



# Proposed Risk Evaluation Guidelines

Annual Accident Frequency (per year) <sup>(a)</sup>	Radiation Dose Consequence to the Maximally Exposed Member of the Public <sup>(b)</sup>	Radiation Dose Consequence to the Worker <sup>(b)</sup>	Risk Acceptability
$\leq 5E-07^{(b)}$	$\geq 750$ rem TEDE <sup>(c)</sup>	$\geq 750$ rem TEDE <sup>(c)</sup>	Acceptable
$> 5E-07$	$> 750$ rem TEDE	$> 750$ and TEDE	Unacceptable
$\leq 1E-06$ and $> 5E-07$	$\geq 25$ and $< 750$ rem TEDE	$\geq 100$ and $< 750$ rem TEDE	Acceptable
$> 1E-06$	$> 25$ rem TEDE	$> 100$ rem TEDE	Unacceptable
$\leq 1E-05$ and $> 1E-06$	$\geq 5$ and $< 25$ rem TEDE	$\geq 25$ and $< 100$ rem TEDE	Acceptable
$> 1E-05$	$> 5$ rem TEDE	$\geq 25$ rem TEDE	Unacceptable
$\leq 1E-04$ and $> 1E-05$	$\geq 1$ and $< 5$ rem TEDE	$\geq 5$ and $< 25$ rem TEDE	Acceptable
$> 1E-04$	$> 1$ rem TEDE	$> 5$ rem TEDE	Unacceptable
$\leq 1E-03$ and $> 1E-04$	$\geq 0.1$ and $< 1$ rem TEDE	$\geq 2$ and $< 5$ rem TEDE	Acceptable
$> 1E-03$	$> 0.1$ rem TEDE	$> 2$ rem TEDE	Unacceptable
$> 1E-03$	$\leq 0.1$ rem TEDE	$\leq 2$ rem TEDE	Acceptable

(a) If applicable for the same package, determination of the accident frequency should account for multiple shipments per year.

(b) The radiation dose consequences are presented as TEDE, which is based on the integrated committed dose to all organs, thereby accounting for direct exposure as well as the 50-Year committed effective dose equivalent.

(c) Accidents with frequencies less than  $5E-07$  per year could be evaluated to confirm there are no cliff edge effects though their likelihoods are extremely low. In general, cliff edge effects should be evaluated.

## Sections of the Report (slide 1 of 4)

Section 1 – Presents an **introduction** to the purpose of study and key events leading up to the study as summarized in Slide 1.

Section 2 - Discussion of the **risk informed regulatory approach** for licensing a TNPP package for maritime transportation, as discussed in Slide 7.

Section 3 - Description of the specific **TNPP Package design concept** defined for the study and the type of **marine vessel assumed** to be used for its transportation.

Section 4 – Proposed **quantitative risk evaluation guidelines** to evaluate the acceptability of the level of risk of maritime TNPP transport, as presented in Slide 8 and 9.

Section 5 - Description of the **general PRA methodology** that can be used to quantify the risk of transportation of a TNPP package for any mode of transportation.

- Updated from the description for domestic highway study.
- Includes comprehensive references to applicable PRA modeling guidance and datasets
- (It is worth noting that unlike for the domestic highway transportation, there is some opportunity for active ship systems in certain accident scenarios to prevent or mitigate the accident)

## Sections of the Report (slide 2 of 4)

Section 6 – Description of the identification and development of **risk dominant maritime TNPP transportation** accidents.

- As with the domestic highway study, an accident is defined as release of radioactive material from the package or loss of shielding leading to increased direct radiation to a receptor.
- Identified from historical risk studies of the maritime transport of qualified Type B packages containing plutonium and irradiated fuel
- The dominant accident scenarios were defined so that they could be treated like the bounding representative accidents specified in the TNPP PRA methodology.

Section 7 - Discussion of the **determination of the likelihoods** of selected maritime TNPP transportation accidents occurring.

- Discusses the event and failure data used to determine accident likelihood.
- Given that INF vessel data are relatively sparse it was augmented with surrogate data for ships carrying hazardous material having the potential to significantly harm or impact a worker or the public (i.e., Liquefied Natural Gas and Liquefied Petroleum Gas)
- Includes, in addition to determination of the initiating event frequencies, determination of conditional probabilities for accident conditions to occur given the initiating event or reduction in accident frequency associated with systems that can prevent or mitigate the event.

## Sections of the Report ( slide 3 of 4)

Section 8 - Discussion of determination of **radiological dose consequences** to a member of the public and a worker from the maritime TNPP transportation accidents established for this scoping study.

- Based on the radiological inventory, the phenomena involved in the accident, the source term for the release, the mobility of that source term (based on factors such as particle size and behavior), the dose pathway, and determining the corresponding radiation dose to a human receptor.
- An accident can cause damage to the package that leads to release of radioactive material or damage to the transport shielding (i.e., external shielding) that does not cause release of radioactive material but could cause an increase in direct radiation.
- The same consequence analysis approach as used for the domestic highway study which is founded on (with certain refinements) the IAEA guidance on performing consequence analysis for determination of quantity limits for radioactive material packages of different types.

Section 9 – Presentation of the **results** of the maritime transportation PRA of a TNPP package and evaluation and **comparison to the proposed risk evaluation guidelines**

- The risk for the accident was considered unacceptable if the radiation dose was exceeded for public or the worker for the frequency range encompassing the estimated frequency of the accident.

## Sections of the Report (slide 4 of 4)

Section 10 - Discussion of **uncertainty analyses and sensitivity studies** performed, and the results obtained.

- Quantitative and qualitative uncertainty analyses were used to define sensitivity studies that help provide risk insights in support of package approval.
- The 95<sup>th</sup> percentile values of the probability distribution determined by quantitative uncertainty analyses of the accident scenario frequencies were used to define sensitivity studies.
- All assumptions and bases listed for major elements of the PRA were qualitatively evaluated for their possible impact on the risk results and sensitivity studies also defined for those deemed to have the potential to impact the risk conclusions

Section 11 - Evaluation of how the **defense-in-depth and safety margin philosophies** are incorporated into the approach.

- Includes discussion of **compensatory** measures that could be credited as a defense-in-depth measures or in a few cases should be explicitly credited in the TNPP transportation PRA.

Section 12 – Discussion of the **conclusions and insights**

- Discusses the feasibility and benefits of applying the risk-informed regulatory approach to maritime transportation of a TNPP package for package approval.

# PRA Risk Results

ID	Accident Frequency per Year <sup>(a)</sup>	Radiation Dose Consequences		Risk Evaluation Guidelines	Meets Proposed Risk Evaluation Guidelines
		Worker (rem TEDE)	Public (rem TEDE)		
Accident Scenario 1 (Collision causing a crush, puncture or shear)	1.0E-06	37	9.2	≥25 and <750 rem TEDE for a member of the public ≥100 and <750 rem TEDE for a worker when the accident frequency is ≤1E-06 and >5E-07	Acceptable
Accident Scenario 2 (Fire)	2.0E-06	0.13	0.004	≥5 and <25 rem TEDE for a member of the public ≥25 and <100 rem TEDE for a worker when the accident frequency is ≤1E-05 and >5E-06	Acceptable
Accident Scenario 3 (Collision Followed by Fire)	1.0E-08	37	9.3	≥750 rem TEDE for a member of the public ≥750 rem TEDE for a worker when the accident frequency is ≤5-07	Acceptable
Accident Scenario 4 (Baseline Crane drop without controls <sup>(b)</sup> )	5.6E-05	69	1.9	≥1 and <5 rem TEDE for a member of the public ≥5 and <25 rem TEDE for a worker when the accident frequency is ≤1E-04 and >1E-05	Unacceptable
Accident Scenario 4 (Crane drop with transport control <sup>(c)</sup> )	5.6E-05	15	1.9	≥1 and <5 rem TEDE for a member of the public ≥5 and <25 rem TEDE for a worker when the accident frequency is ≤1E-04 and >1E-05	Acceptable

**Note:**

(a) It is assumed that one transport occurs in a year.

(b) Risk is considered unacceptable without application of additional controls and/or compensatory measures.

(c) The transport control is defined as a set of administrative requirements and/or barriers that limit the distance a worker could be from a dropped TNPP package to 25 meters or radiation protection for the worker, such as the use of HEPA filtration, that provides equivalent protection.

# Results and Insights

Concerning the **uncertainty analyses and sensitivity studies** (slide 1 of 3):

- Two sensitivity studies that were performed suggest measures that could be used to **reduce the risk from Accident Scenario 4 (crane drop) to an acceptable level** (1) increasing the distance a worker can potentially be from a dropped package, and (2) using a loading and unloading process that doesn't involve a crane lift (e.g., by using a transport vessel with roll-on/roll-off capability).
  - That said, other measures could be conceived given more specific information on the crane, dock and ship configuration, and actual loading and unloading procedures.
- Some sensitivity studies show that the uncertainty associated with factors that could impact risk **do not change conclusions about risk** for the accidents studied. For example:
  - For the uncertainty associated with the **release fractions** (Release fractions refer to the fraction of radioactive material that is released from the TRISO fuel during reactor operation and is diffused into or attenuated in the reactor core and plated out in the cooling system) use of the 95<sup>th</sup> percentile of the probability distribution rather than the mean does not change the risk conclusions.
  - The uncertainty associated with **factors that impact the severity of an onboard fire** such as generation of a plume has little effect on the risk results primarily because of the minor contribution that fire makes as an accident release phenomena on the dose consequences.

# Results and Insights

Concerning the **uncertainty analyses and sensitivity studies** (slide 2 of 3):

- However, other sensitivity studies also showed that modeling uncertainty **could change the conclusions about risk** for some accidents. In these cases, compensatory measures could be chosen that reduce the risk of these accidents.
  - The uncertainty associated with source term factors can impact the conclusion about risk for a specific accident. Source term factors are used to define how much radioactive material is released from an accident based on the physical conditions and phenomena created in the accident.
    - ✓ Therefore, it may be beneficial to identify compensatory measures that are designed to specifically decrease the damage to TNPP Package or contain release of airborne particles.
  - A sensitivity study on the uncertainty associated with the conditional probability of damage of concern given collision (Accident Scenario 1) indicates using a higher probability results in an unacceptable level of risk
    - ✓ Therefore, it may be beneficial to identify compensatory measures that are specifically designed to decrease the likelihood of collision
- Some studies were performed in which the sensitivity case was assumed to be **more favorable than the baseline case** in the event it could be used as a basis to manage unacceptable risk. However, most of these studies did not show enough risk reduction to change the risk conclusions
  - Reduction of reactor life from 10 to five years. Increase of decay time from one to two years. Decrease in the conditional probability of package damage given a crane event from 50 percent to 10 percent.

# Results and Insights

Concerning the **uncertainty analyses and sensitivity studies** (slide 3 of 3):

- The results of one sensitivity study indicates that there could potentially be some underestimation of risk associated with maritime transportation of a TNPP Package because this scoping study does not comprehensively try to address all possible accident scenarios including low consequence high frequency events.
  - Therefore, future study (or an application that involves a specific design), should include comprehensive hazards analysis to identify and develop a full range of accident scenarios so they can be evaluated.
- As mentioned earlier it is required that **“cliff edge effects”** be identified and investigated when the risk evaluation guidelines are applied
  - As it turns out no sensitivity study was performed on a possible cliff edge effect, but special investigation of the cliff edge effect was performed prior to uncertainty analysis during accident sequence development.
  - The special evaluation concluded that no credible conditions could exist in a shipboard fire (even after a collision) in which temperatures could approach the threshold for release of radionuclides from the TRISO fuel.
  - If such an event were possible it would dramatically increase the radiation dose to a receptor from such a fire.
  - As stated earlier in the presentation, the proposed risk evaluation guidelines state that potential “cliff edge effects” should be investigated. They could be investigated using a sensitivity study but, in this case the potential effect was considered important enough to perform a special evaluation.

# Results and Insights

## Concerning the **defense in depth and safety margins**:

- Defense-in-depth and safety margin philosophies are **not explicitly incorporated in** U.S. or international regulations on radioactive material packaging.
  - However, they are key concepts in ensuring the nuclear safety of NPPs and nonreactor facilities including when using PRA for risk-informed applications in the U.S. and internationally.
- Defense-in-depth is a design and operational philosophy that calls for multiple layers of protection to prevent and mitigate accidents. **Key elements of defense-in-depth** include:
  - Robustness of the TRISO fuel in providing a confinement and/or shielding function in addition to the TNPP, the TNPP module CONEX-box like structure, and the ship hold
  - The range of features and systems built into the transportation vessel to prevent and mitigate the risk of accidents
- Safety margin is a **measure of the conservatism** that is employed in a design or process to assure a high degree of confidence that it will perform a needed function
- After their evaluation, it is concluded that defense-in-depth and safety margin philosophies can generally be applied consistent with NRC and international guidance and expectations in support of a maritime transportation PRA of a TNPP.
- As such, the implementation of compensatory measures is an approach that **aligns with the defense-in-depth philosophy** and has the effect of reducing risk

# Results and Insights

- **Compensatory measures** could include considerations such as (Slide 1 of 2):
  - Compensatory measures that could be credited quantitatively (as a formal transportation control) for **reducing risk associated with crane drop accident to an acceptable level**
    - Eliminating the need for crane lift
    - Control of the distance that a worker could potentially be to the TNPP Package should it be damaged during loading and unloading.
    - Control of the height that a package can be lifted above an unyielding surface during loading and unloading.
    - Worker use of protective clothing against radiation exposure and use of personal HEPA filtration
    - Use of impact absorbing or drop limiting features during loading and unloading of the TNPP Package.
  - Compensatory measures for **reducing the likelihood associated with the collision accident**
    - Using shipping lanes that have less traffic.
    - Leaving and entering ports at times of reduced traffic.
    - Conducting the transport with an escort ship that is also keeping track of the position of other ships.
  - Compensatory measure needed **to protect an underlying assumption used in the PRA**
    - Precluding materials that can cause explosions and potentially damage the TNPP Package from being transported as cargo at the same time as the TNPP Package.

## Appendices of the Report (slide 1 of 3)

### Appendix A

Presents a description of a visit by representatives that included part of the PNNL team to Nuclear Transport Solutions (NTS) in Barrow U.K. June 17, 2024

- The topic of discussion was about maritime transportation of radioactive material and how packaging approval could be performed using a risk informed approach and tour of an INF ship
- The material provided in the report summarizes discussion and includes design and safety details of the INF ship that was toured and answers to specific questions from the PNNL-led team about an INF ship and its history

### Appendix B

Presents description of an estimate of total NTS fleet miles as an initial step in estimating event frequencies

### Appendix C

Presents assessment of a potential cliff edge effect in fire event consequence determination

- A cliff edge effect is a case in which a small change in the analysis assumptions could potentially cause a disproportionate change in the radiological consequences.
- In this case, the concern was whether temperatures during bounding shipboard fires could approach the threshold for release of radionuclides from the TRISO fuel.

## Appendices of the Report (slide 2 of 3)

### Appendix D

Presents an evaluation of the maritime collisions in the surrogate dataset that could potentially cause damage to a TNPP package given the conditions of the accident and assumption that a TNPP package is being transported.

- This was done to determine a condition probability that the TNPP package is damaged given the collision

### Appendix E

Presents an evaluation of the maritime fire events in the surrogate dataset that could potentially cause damage to a TNPP package given the conditions of the accident and assumption that a TNPP package is being transported.

- This was done to determine a condition probability that the TNPP package is damaged given the fire event

### Appendix F

Presents determination of a TNPP radionuclide inventory to use in the demonstration PRA consequence analysis

- Is estimated from available data and takes into consideration release of fission products and actinides from the fuel during operation that diffuse elsewhere (e.g., the core and cooling system)

## Appendices of the Report (slide 3 of 3)

### Appendix G

Presents the scripts that were used in the uncertainty analysis to estimate probability distributions for the initiating events and to estimate the 95<sup>th</sup> percentile values to use in the sensitivity studies.

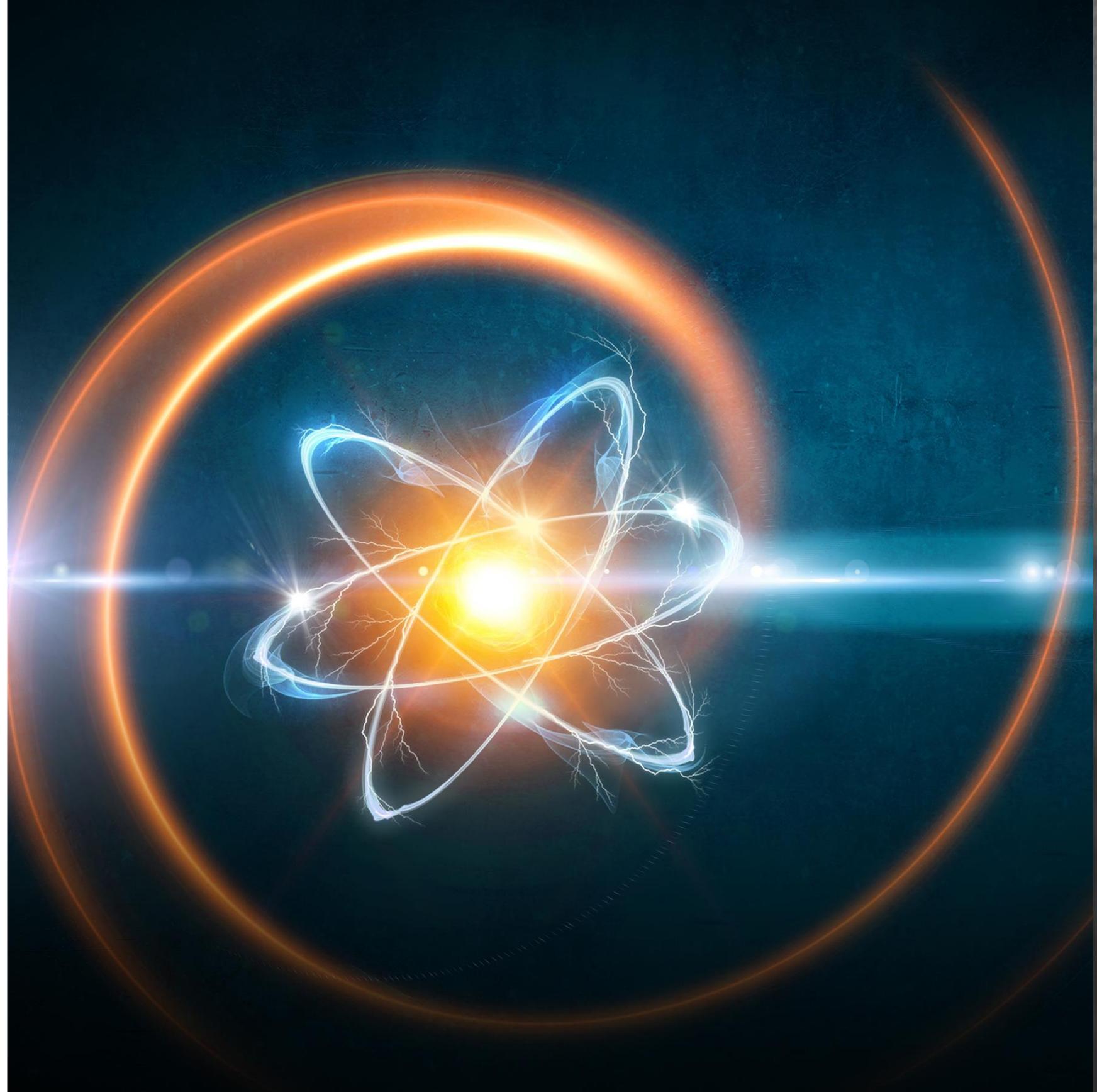
# Final Thoughts

- This demonstration shows the workability and feasibility of applying the risk-informed approach reviewed by NRC for domestic highway transportation to maritime transportation.
- The demonstration shows how the process would work and how quantitative risk results and insights could be used to support package approval.
- This demonstration includes investigation into relevant international nuclear regulations and concludes there is general alignment with the risk-informed regulatory approach proposed for maritime shipment of a TNPP package.
- More work could be done to demonstrate the approach using:
  - An actual detailed TNPP package design
  - Detailed information about an actual transport vessel and operational procedures (e.g., particularly for loading and unloading the TNPP Package)
  - More comprehensive identification of accident scenarios and defining of bounding representative accidents

# References

- **10 CFR Part 71.** 2023. “Packaging and Transportation of Radioactive Material. Code of Federal Regulations,” U.S. Nuclear Regulatory Commission. Available at <https://www.govinfo.gov/app/collection/cfr/2023/>
- **Coles, G.A. et al. 2024.** *Development and Demonstration of a Risk Assessment Approach for Approval of a Transportation Package of a Transportable Nuclear Power Plant for Domestic Highway Shipment*, PNNL-36380, Revision 1, Pacific Northwest National Laboratory, Richland, Washington, August 2024.
- **IAEA. 2018.** *Regulations for Safe Transport of Radioactive Material*, Specific Safety Requirements (SSR) 6, Revision 1, International Atomic Energy Agency (IAEA), Vienna Austria, 2018. Accessed at <https://www.iaea.org/publications/12288/regulations-for-the-safe-transport-of-radioactive-material>.
- **NRC. 2008.** *Risk-Informed Decisionmaking for Nuclear Material and Waste Applications*, Revision 1, U.S. Nuclear Regulatory Commission, Washington, D.C., February 2008. Accessed at <https://www.nrc.gov/docs/ML0807/ML080720238.pdf>.
- **NRC. 2024a.** *Endorsement of the Risk Assessment Approach for Transportation Package Approval of the Project Pele Transportable Nuclear Power Plant for Domestic Highway Shipment*, Letter from NRC, U.S. Nuclear Regulatory Commission, to Waksman, Jeff, Strategic Capabilities Office, U. S. Department of Defense, Chantilly, VA. dated October 7, 2024. Accessed at <https://www.nrc.gov/docs/ML2427/ML24271A054.pdf>.
- **NRC. 2024b.** *U.S. Nuclear Regulatory Commission Review of the Risk Assessment Approach for Transportation Package Approval of the Project Pele Transportable Nuclear Power Plant for Domestic Highway Shipment*, Letter (and Enclosure containing the method evaluation) from NRC, U.S. Nuclear Regulatory Commission to Waksman, Jeff, Strategic Capabilities Office, U. S. Department of Defense, Chantilly, VA. dated August 5, 2024. Accessed at <https://www.nrc.gov/docs/ML2332/ML23321A132.pdf> and <https://www.nrc.gov/docs/ML2332/ML23321A133.pdf>

# Questions & Discussion



# Back Up Slides

## Need for Risk-Informed Regulatory Approach and Basis for Proposed Regulatory Approach

- A TNPP with its irradiated fuel contents prepared as a package for transport could be challenged to meet the entire suite of regulatory performance requirements in 10 CFR 71 as they are intended for thick-wall steel vessel for SNF transportation package
  - It is anticipated that the TNPP will be capable of being deterministically shown to comply with the Normal Conditions of Transport (NCT) as outlined in 10 CFR 71.71
  - However, it may be challenging to demonstrate that the level of robustness of current proposed TNPP technology can fully meet the dose rate and containment success criteria after Hypothetical Accident Conditions (HAC) tests as outlined in 10 CFR 71.73
    - ✓ E.g., Sequential 30 ft free drop, crush, puncture free drop, 30-minute engulfing hydrocarbon fire, and water immersion tests
- Leverage compensatory measures, defense-in-depth approaches, and philosophies *to establish equivalent safety*. Also leverage consideration of TRISO, compact, fuel sleeve, core, and reactor structure related inherent retention and protection boundaries
- If Fissile Material or Type B package postulated HAC requirements (10 CFR 71.73) cannot be directly met, then other options such as 10 CFR 71.41(c), 10 CFR 71.41(d), or **10 CFR 71.12 (Specific exemption)** are possible
- Preferred initial pathway identified by PNNL is the **Specific exemption** process that allows compensatory actions to protect the basis of the exemption if acceptable risk is demonstrated
  - Can apply to more than a single shipment unlike Special Package Authorization (10 CFR 71.41(d))
  - Flexibility in deviating from deterministic requirements compared to Alternative Environmental and Test Conditions

## Reasoning Behind Selection of this Regulatory Approval Pathway

- Quantitative risk analysis approaches such as Probabilistic Risk Assessment (PRA) are used in risk-informed regulatory approaches for the NRC:
  - PRAs have been conducted since the 1970s for nuclear reactors starting with WASH-1400 and used since the 2000s for risk informed licensing applications.
  - PRA has also been used to assess:
    - ✓ Dry cask storage systems at a nuclear power plants (see NUREG-1864)
    - ✓ Transportation of spent nuclear fuel (SNF), most notably in NUREG/CR-4829, NUREG/CR-6672, and NUREG-2125
    - ✓ Risks of transporting SNF to the Yucca Mountain repository by truck and rail (DOE/EIS-0250)
- Proposed to NRC as an aid in developing a near-term approval pathway to drive Advanced Factory-Produced TNPP development and deployment
- Bridges the gap between the current regulatory framework (thick-wall steel vessel based) and the level of robustness of current proposed TNPP technology
- Provides buffer time for strategic regulatory considerations and possible rule making to accommodate advanced, transportable, microreactor conventions

## Applying the Proposed Risk Informed Licensing Methodology to a Draft NRC Safety Evaluation/Safety Analysis Report (SAR) Application

For an applicant to receive transportation package licensing approval, they must develop a complete transportation package safety basis as part of their application that demonstrates reasonable assurance of adequate safety to the public, worker, and environment is provided. This would involve:

- An assessment of all influencing physical, chemical, and environmental loading conditions that would adversely affect package performance when considering all disciplines (structural, thermal, containment, shielding, criticality, operations, and acceptance) to verify maintenance of subcriticality, retention of radionuclide inventory, and adequate shielding and thermal management
- Application of all applicable consensus standards (e.g., ASME Codes and Standards), NRC Transportation (Division 7) Regulatory Guides (e.g., Regulatory Guide 7.1 - 7.13), NRC Standard Review Plans (e.g., NUREG-2216), etc., and using Regulatory Guide 7.9 as standard format and content guidance of Part 71 applications to:
  - Deterministically demonstrate TNPP package compliance with dose rate and containment success criteria after Normal Conditions of Transport (NCT) as outlined in 10 CFR 71.71
  - Deterministically demonstrate TNPP package compliance with dose rate and containment success criteria after Hypothetical Accident Conditions (HAC) tests as outlined in 10 CFR 71.73 or fully exploit the design to determine the level of robustness and capacity to meet these requirements
  - Develop legitimate compensatory measures while employing quantitative risk assessment using an integrated assessment process based on PRA methods which includes use of sensitivities and uncertainty analysis and consideration of DID and SM to reestablish equivalent safety only for those challenges identified through a rigorous screening of HAC related assessments
  - Request that NRC consider an exemption following the process outlined in 10 CFR 71.12 and leverage the substantiating information from the previous step to protect the basis of exemption and demonstrate acceptable risk