SAND2022-7602C

Sandia National Laboratories

Nuclear Reactors and The Arctic

Environmental Impact Modeling and MACCS

Kyle A. Clavier, PhD

Mariah L. Smith

Daniel J. Clayton, PhD

John D. Fulton

The Arctic Institute: Polar (In)Securities: The Future of Global Affairs in the Circumpolar North

Friday, June 10th 2022

U.S. DEPARTMENT OF ENERGY | NNSA

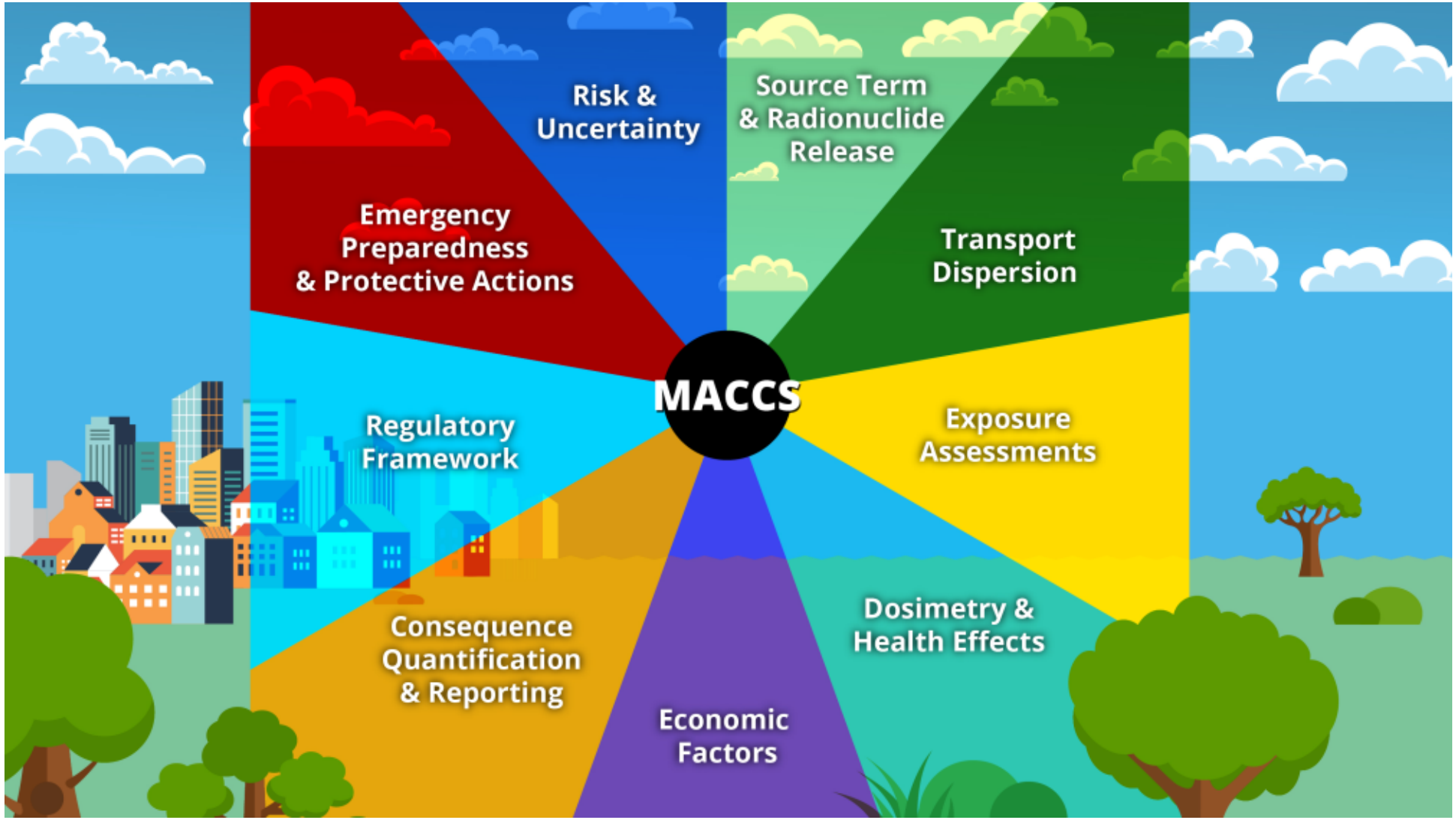
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

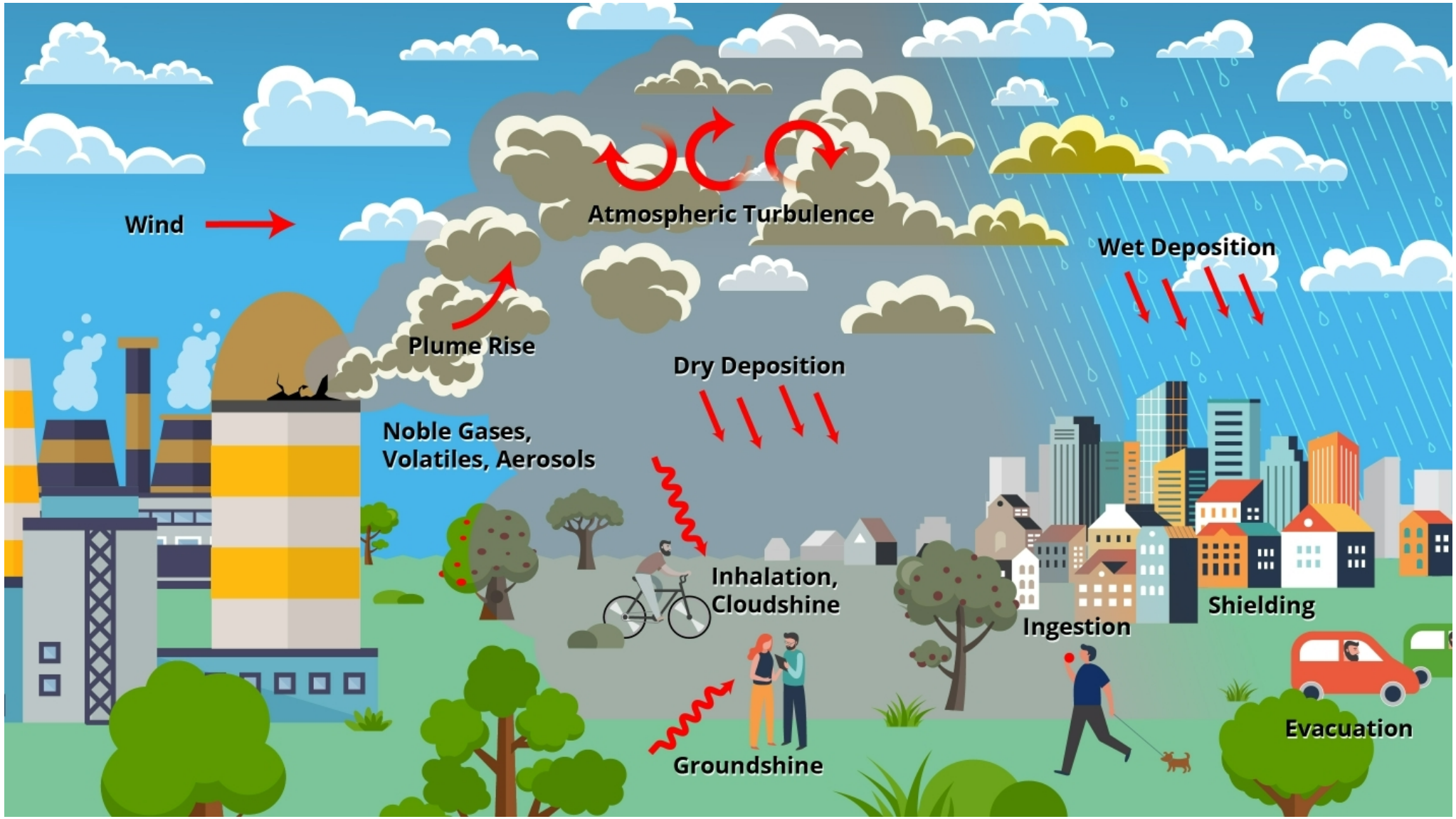
Overview

- Introduction to MACCS
- Discussion on the potential role of nuclear for Arctic energy security
- Discussion on the unique challenges the Arctic presents for consequence analysis modeling
  - Floating reactors
  - Vulnerable food chains
  - Socioeconomics
  - Arctic meteorology
  - Dose coefficients
- Summary and concluding remarks

MACCS is a powerful computer code used to simulate the impact of severe nuclear accidents on the surrounding environment



MACCS excels in modeling traditional terrestrial environments



Decades of development has resulted in the modern MACCS code

Chernobyl
1986
(Getty Images)

Three Mile Island
1979
(Getty Images)

Fukishima-Daiichi
2011
(Getty Images)

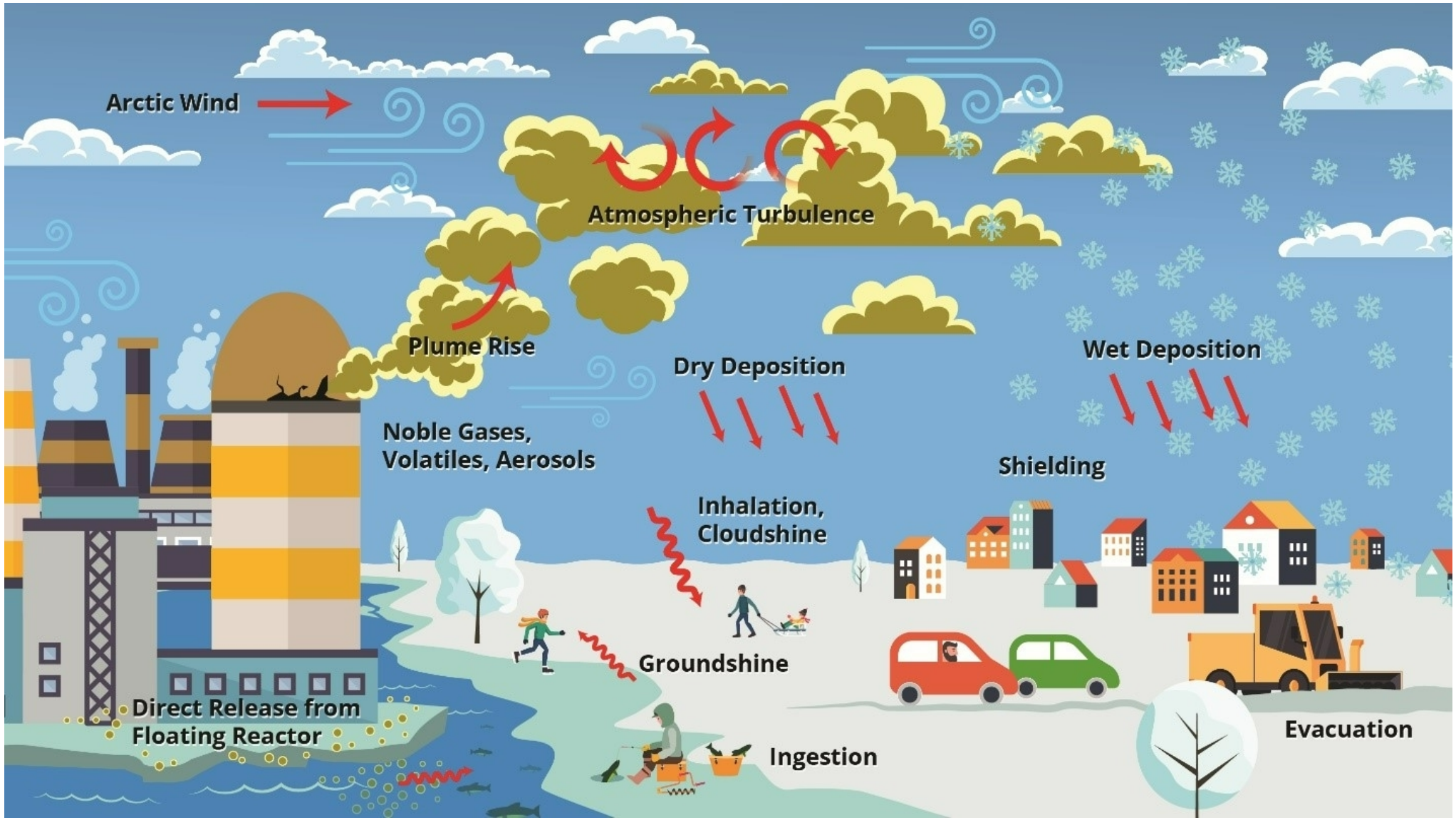
Nuclear is expected to play a role in a secure energy future for the Arctic

- Small carbon footprint
- Reliable energy source
- New generation of advanced reactors (e.g., HTGR, MSR) are advertised as being safer and cheaper per kWe
- Traditional renewables (e.g., wind, solar, hydropower) are challenging in harsh environmental conditions of Arctic
- Mobile, waterborne reactors already implemented with more on the horizon

Consequence analysis and probabilistic risk assessment have historically been used to evaluate safety and emergency preparedness

Appropriately modeling risk ensures a safe and equitable transition to nuclear energy in the Arctic

MACCS is well-equipped to quantify nuclear accident risk in the Arctic



Arctic environments present unique challenges for traditional consequence analyses using the available modeling space

Operational floating reactors have evolved from a concept to a practically applied technology with strong potential for the Arctic

- Recently deployed mobile floating reactors in Arctic environments (Russia, UK, South Korea)
- Some companies internationally have seen a surge in development of floating reactor technology
- Floating reactors offer mobile/flexible carbon-free energy for communities that lack expensive infrastructure necessary to accommodate power generation facilities
- Design/construction/operation/maintenance of traditional power generation facilities may be difficult
- **Waterborne reactors present unique challenges not currently addressed by existing modeling capabilities**
  - **Coupled aqueous and atmospheric transport**
  - **Ice melt and transport**
  - **Washout during arctic snowstorm**

Arctic regions may have uniquely vulnerable food chains, especially for indigenous communities

- Arctic food chains may not fit the traditional mold of terrestrial food chain
  - Difficult to cultivate certain fruits and vegetables
  - More heavily reliant on aquatic food (fisheries disproportionately impacted by accident scenario)
  - Relative isolation from global supply chains
  - Landlocked communities may rely on subsistence hunting of unique animals
- **Existing food chain models may not currently address Arctic challenges**
  - **Expanding fruits/vegetables considered**
  - **Expanding 'other animals' category**
  - **Weight traditional food groups differently**
  - **Implement radionuclide transport properties for aquatic and arctic wildlife tissue**
- MACCS code suite includes robust food chain modeling capabilities (COMIDA2)

Nuclear accidents in the Arctic may have comparatively disproportionate socio-economic impact

- Arctic presents new challenges associated with extremely limiting habitable or farmable land area
- Monetary losses ascribed to condemned land may not appropriately account for true socioeconomic loss (more significant fraction of total habitable/farmable land)
- Impacted population would presumably have a much more limited range of options to resettle
- Arctic industries highly localized and prone to disruption (e.g., fisheries)
- Relative isolation presents challenges to recovery from an accident
- Infrastructure presents challenges to evacuation
- **Nuclear accident codes need to appropriately treat the unique socioeconomics of the Arctic:**
  - **Revised socio-economic impact model**
  - **Revised evacuation models**
  - **Quantify economic cost associated with delayed recovery**
- MACCS is equipped with a robust economic impact model

Arctic meteorology presents unique modeling challenges

- Current atmospheric modeling capabilities are in need of enhancements to better address unique arctic meteorological issues and advanced reactors consideration.
  - Ice fog
  - Near field dispersion
  - Dynamic plume rise

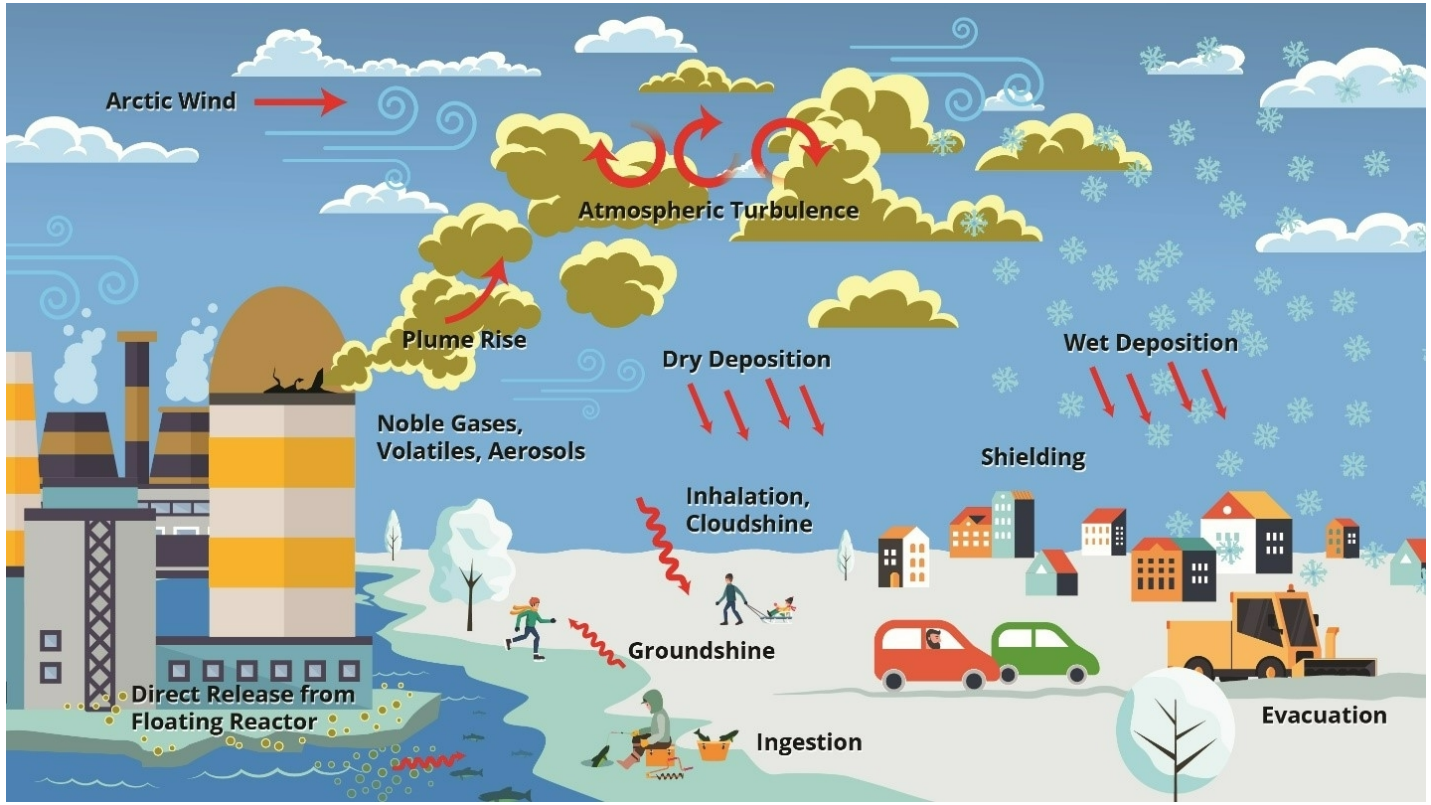
Source: https://www.forbes.com/sites/marshallshepherd/2016/12/21/yep-freezing-fog-is-real/?sh=2d1386525771

Dose coefficients may be entirely different for indigenous populations

- Dose coefficients translate a radionuclide intake to an effective dose to an individual
- Dose coefficients depend on aspects such as gender and other physiological parameters
- Dose coefficients may be applied too broadly
- Updating dose coefficients to accommodate broader swaths of the population is an active area of research
- Indigenous populations may be impacted the most
- It is critically important to have accurate dose coefficients for different cohorts of people
- **Dose coefficients in accident consequence codes should appropriately quantify risk to all impacted populations**

Summary

- Probabilistic risk assessment (PRA) is a valuable tool for assessing nuclear implementation risks in the Arctic
- Existing modeling space would benefit from additional research, in order to pre-empt a transition to nuclear energy use in the Arctic
  - Floating reactors
  - Food chain impacts
  - Socioeconomics
  - Arctic meteorology
  - Dose coefficients
- Investment in these areas will ensure a safe, equitable and reliable energy future for the Arctic that also minimizes the carbon impact associated with energy generation



Thank you! Questions?

Contact Information:

Kyle A. Clavier, PhD, Senior Geosciences Engineer, Sandia National Laboratories

kaclavi@sandia.gov

Mariah L. Smith, Geosciences Engineer, Sandia National Laboratories

msmith7@sandia.gov

Daniel J. Clayton, PhD, Principal Nuclear Engineer, Sandia National Laboratories

djclayt@sandia.gov

John D. Fulton, Manager, Sandia National Laboratories

jdfulto@sandia.gov