Basis for Regulatory Requirements: Design and Safety Analysis of New Reactor Facilities

International Conference on SMRs and their Applications, IAEA, Vienna

21-24 October 2024

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Building on Strength

Introduction

Rethinking **safety criteria** to address differences in risk profile of SMRs compared to traditional nuclear power reactors (NPPs)

Shift the regulatory lens on **balancing risks and benefits** to ensure alignment with *IAEA Fundamentals* - Safety Principles 4, 5, and 6

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IAEA Safety Fundamentals - Principles 4, 5 & 6

- **IAEA Safety Principle 4:** Nuclear risks must be justified by benefits
- **IAEA Safety Principle 5**: Regulations should match the magnitude of the radiation risks
- **IAEA Safety Principle 6**: Optimization of protection and safety should be applied for workers, the public, and the environment

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US NRC Policy Statement on Safety Goals:

Example - Application of IAEA Safety Principles 6 & 4

IAEA Principle 6: Limitation of Risks

- *"Individual members of the public should be provided a level of protection from the consequences of nuclear power plant operation such that individuals bear **no significant additional risk** to life and health"*

IAEA Principle 4: Justification of Risks

- *"Societal risks to life and health from nuclear power plant operation **should be comparable to or less than** the risks of generating electricity by viable competing technologies and **should not be a significant addition to other societal risks**"*

Ref: *Nuclear Regulatory Commission, 51 FR 30028, Policy Statement: Safety Goals for the Operation of Nuclear Power Plants*, (1986)

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SMRs and Large NPPs

Key Differences for Regulatory Considerations

- **Reactor Size & Output**: Smaller power output per unit (up to 300 MW(e))
- **Design Complexity**: Inherently safer designs and more simplified safety systems – fewer systems, passive cooling mechanisms
- **Modularity:** Designed to be deployed in a modular fashion, allowing multiple units the same site
- **Flexibility and Siting:** Can be deployed in diverse, remote, or smaller-grid locations, and do not require substantial infrastructure
- **Operational Flexibility:** Can be operated independently or scaled incrementally to meet demand, and do not require continuous full-load operation
- **Environmental and Community Impact:** Reduced environmental footprint and more limited offsite releases impact protection zones due to smaller source term

Risk-informed Decision-Making

NPP safety criteria do not effectively balance risks with the benefits of SMRs.

- **Fixed dose limits** fail to consider different reactor sizes and outputs.

Adjust safety criteria to balance risk and benefits, setting criteria based on energy output rather than per reactor.

- Risk assessment must compare the safety of SMRs to **alternative energy generation methods**, like fossil fuels or renewables.
- Compare SMR risks to **public health risks**, such as cancer rates in OECD countries – using ICRP Risk Coefficients
  - For highest frequency DBA, risk rises from 21% to 21.42% for most exposed person – small but not insignificant
  - For lowest frequency DBA, risk rises from 21% to 21.00042% for most exposed person – insignificant

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Current Safety Goals: Issues & Limitations
Probabilistic Safety Assessment (PSA)

- **Focus on Severe Accidents**
  - Current safety goals primarily manage risks from severe accidents, leaving low-dose, **high-frequency/low-consequences** accidents largely unaddressed.
    - These events, though frequent, have no PSA safety goals, leaving a gap in overall risk management
- **PSA safety goals are typically set 'per reactor'**
  - Small reactors release greater fraction of radioactive inventory and still meet goals
  - No account of number of reactors needed to meet generation demand
- **PSA's Strength**
  - PSAs offer a stronger **basis for risk-informed** safety assessments – managing risks across all accident frequencies

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Current Safety Goals: Issues & Limitations
Deterministic Dose Criteria

- **Fixed Dose Limits Across Decades of Frequency Range**
  - Deterministic Safety Analysis (DSA) dose limits applied to individual accidents and remain **fixed across a wide range of accident frequencies**, regardless of their likelihood
- **No Consideration of Reactor Size/Number**
  - Size or number of reactors on a site is not factored into dose criteria - **same criteria are applied to each reactor**, whether a site has one large or several small reactors (SMRs)
- **Control over Number of Accidents**
  - Number of potential accidents is not regulated
  - Lack of **cumulative safety goal** for accidents within the design basis gives no credit to simpler designs

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Cumulative Risk Targets

- Introduce **cumulative risk** as the total risk from multiple potential accidents within the **design basis**
  - **Deterministic safety analyses** focus on individual accident limits but don't account for cumulative risks from multiple reactors or frequent smaller events

Ref: NEI 18-04 Revision 1, *Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development*

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Conclusion & Recommendations

Current safety goals do not fully align with IAEA Safety Principles (4, 5, 6)

Balance risks with benefits

- **Compare** SMR risks to those of other energy generation methods (fossil fuels, renewables)
- Set **risk criteria** based on **energy output**, not "per reactor”

Introduce cumulative risk targets

- Add a **cumulative risk safety goal** for all postulated accidents within the design basis

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Thank you!

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Additional slides – Reference Material

IAEA Safety Fundamentals Principles 4, 5, & 6

- ***Principle 4****:* Justification of Facilities and Activities:

  Facilities and activities that give rise to radiation risks must provide an overall benefit.

  > *"...to be considered justified, the **benefits** that they yield **must outweigh the radiation risks** to which they give rise"*

- ***Principle 5***: Optimization of Protection

  Protection must be optimized to provide the highest level of safety that can reasonably be achieved.

  > *"... the scope and stringency of regulations and their application, have to be **commensurate with the magnitude of the radiation risks**..."*

- ***Principle 6***: Limitation of Risks to Individuals

  Measures for controlling radiation risks must ensure that no individual is subjected to unacceptable radiation risks.

  > *"... doses and **radiation risks must be controlled within specified limits**"*

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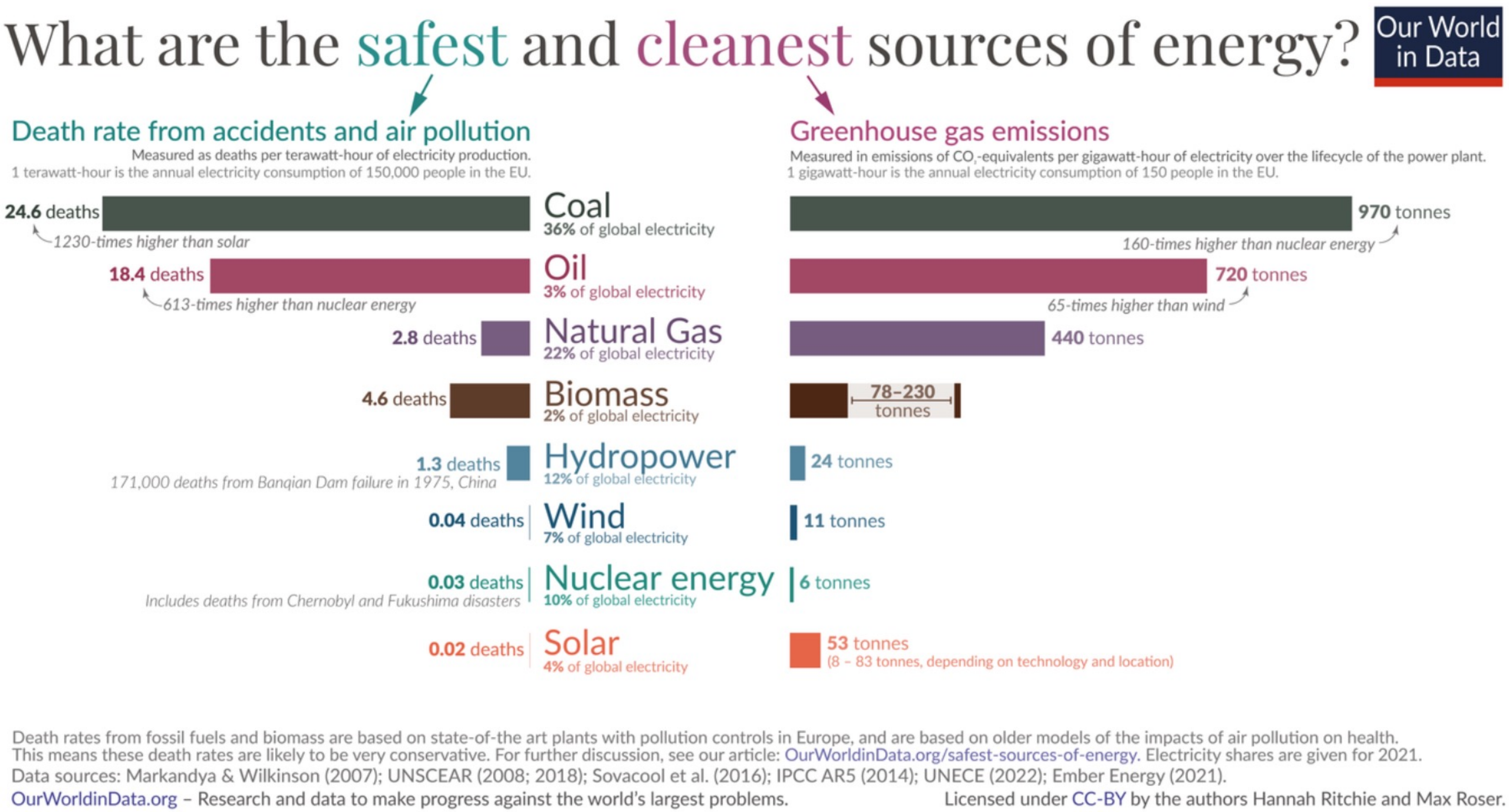
Comparison of Energy Generating Technologies



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Nuclear Power Strategies/Policies

Example:

Countries adopted different strategies for power generation
https://app.electricitymaps.com/

Example – DSA Risk

- For high frequency DBA (10^{-2} /y), giving limit dose of 20 mSv and using ICRP Pub 103 risk coefficient for cancer of 0.055 Sv^{-1},
  - Risk of cancer = 0.055 x 10^{-2} x 0.02 = 1.1 x 10^{-5} /y
  - Background risk of cancer is ~21% in OECD countries
  - Annual risk is 2.616 x 10^{-3} /y based on life expectancy of 80.3 y
  - High frequency DBA increases lifetime risk of a fatal cancer from 21% to 21.42% - small increase but **not negligible**
- Repeating for low frequency DBA (10^{-5} /y):
  - Low frequency DBA (10^{-5} /y) increases risk from 21% to 21.00042%
  - This risk increase is **insignificant**
- **Constant limit across several decades of frequency is not risk-informed**

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