Sandia National Laboratories

Interactively Mapping the Global Nuclear Fuel Cycle

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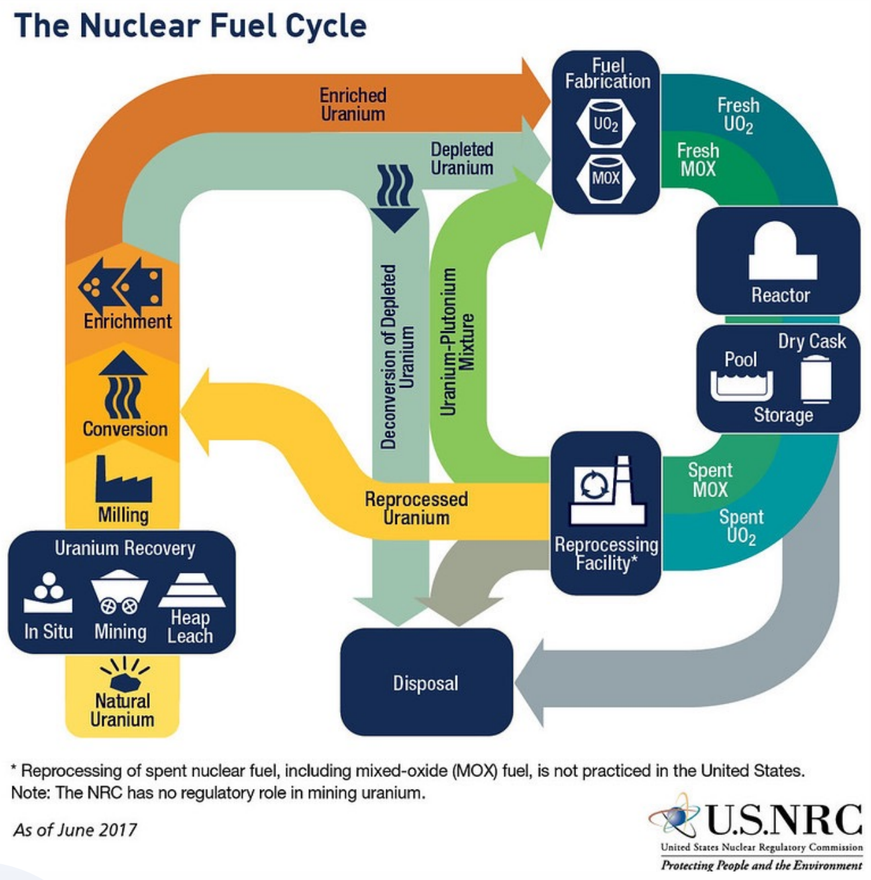
BACKGROUND

- Nuclear power stands as a **low-carbon energy source**, a pivotal role in mitigating greenhouse gas and addressing the challenges of climate change
- Nuclear power's high energy density enables efficient electricity generation from a small amount of fuel, meeting **large-scale energy demands** – approximately 20,000x - 30,000x more electricity per metric ton compared to coal or natural gas
- Technological advancements driven by the Nuclear Fuel Cycle (NFC), including reactor design, fuel reprocessing, and waste management**, foster progress** within the realm of nuclear power but **contemporaneously in diverse fields** such as medicine, industry, and space exploration
- Crucially the NFC involves the production and **handling of fissile materials**, enriched uranium or plutonium, with potential for diversion towards the development of nuclear weapons
- **Illicit acquisition** of these materials poses a significant risk, leading to nuclear proliferation and security threats



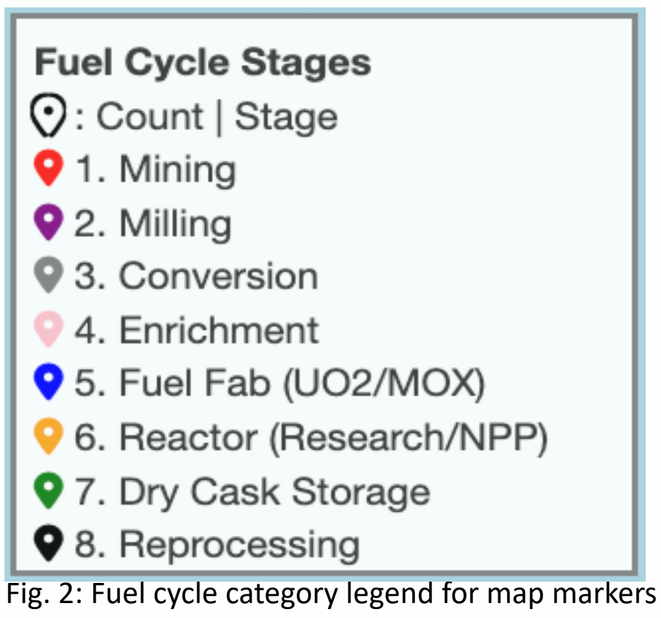


Fig. 2: Fuel cycle category legend for map markers

PROCESS

- Conduct Exploratory Data Analysis (EDA) on the original data to incorporate synthetic geometry data
- Generate plots to visualize the sites within the dataset
- Condense data from 1100 records with 10 features to 240 records with 12 features by **grouping site types** by countries rather than quantity, producing a more **streamlined dataset**
- Implement color organization based on the fuel cycle to enhance data visualization
- Develop a functionality where selecting a map marker displays the complete fuel cycle information
- Introduce a **new feature** called *CoordPath* that assigns a path consisting of ordered site coordinates to each record, representing the completion of its cycle

TOOLS: Data For Nuclear Network Modeling, Python, Nominatim, Folium, Geopandas

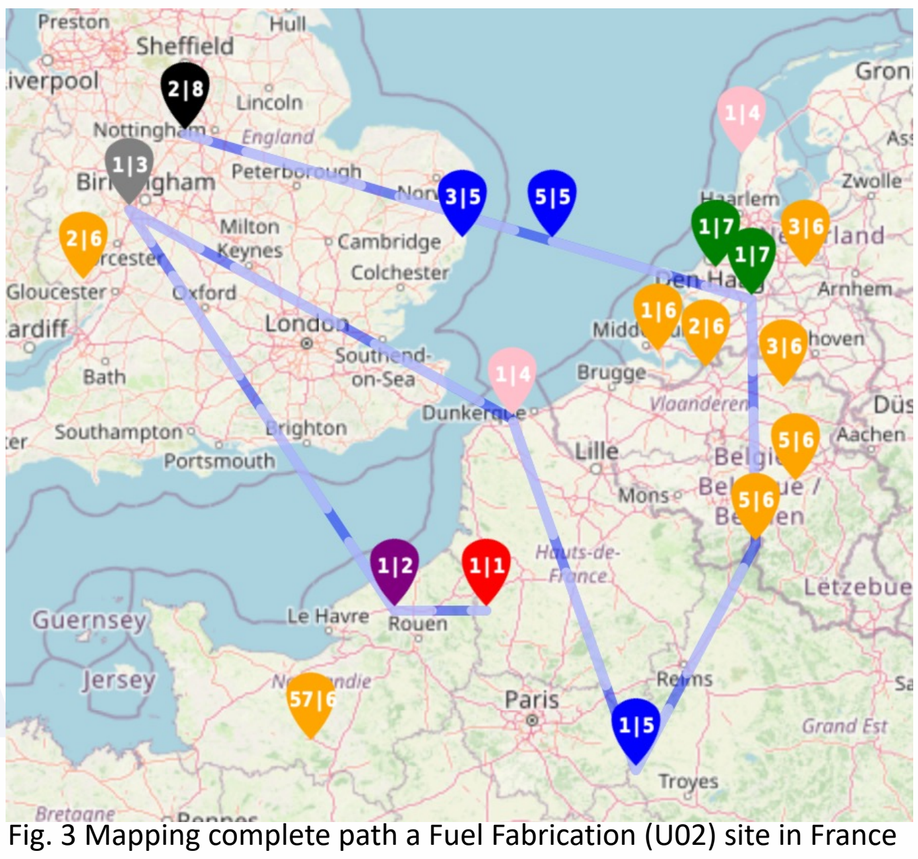


Fig. 3 Mapping complete path a Fuel Fabrication (U02) site in France

RELEVANCE

Premise

- Graphically reflect the global NFC considering the geography of the fuel cycle process on account of the NFC encompassing both **inherent risks and notable benefits**

Emergence

- Given the emergence of new countries entering the NFC or serving as transit routes for nuclear materials, comprehending the **intricate movement** of NFC material assumes paramount importance

Awareness

- Understanding facilitates **enhanced** situational awareness and enables implementation of **effective risk mitigation** strategies safeguarding against potential threats

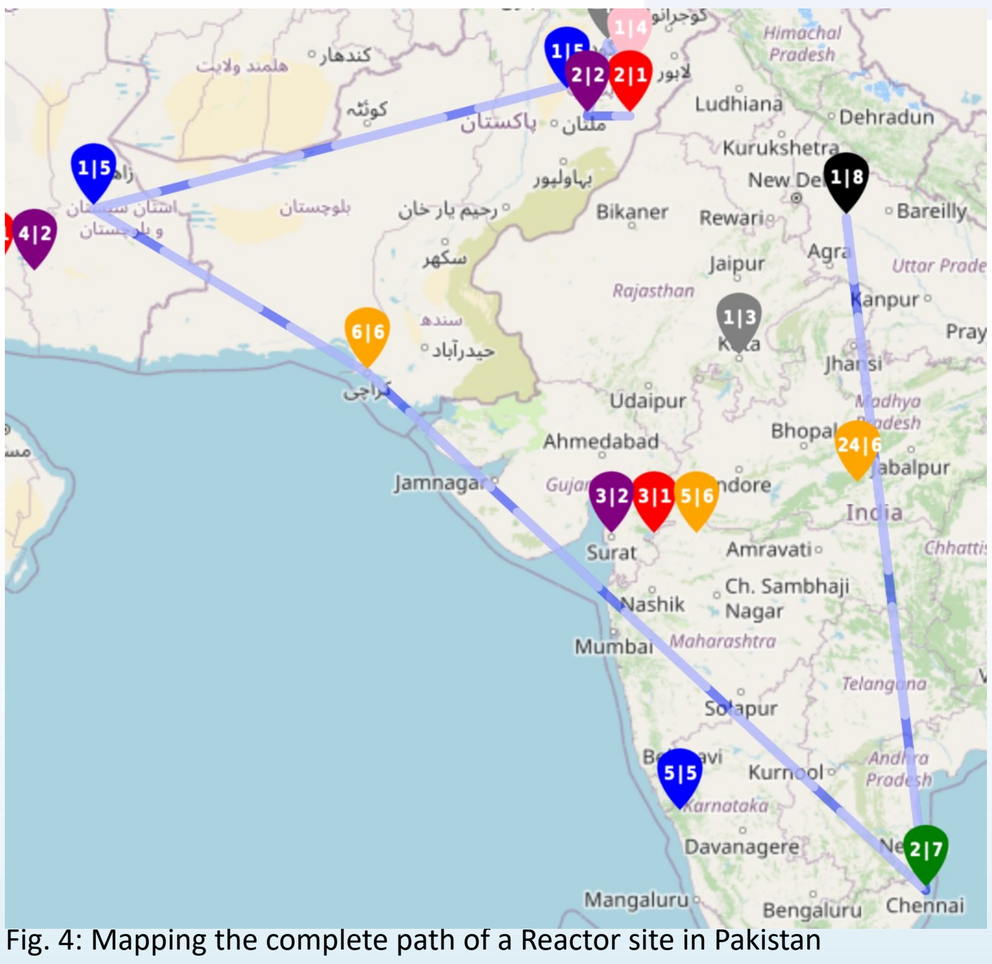


Fig. 4: Mapping the complete path of a Reactor site in Pakistan

SIGNIFICANCE

Refine

- The analysis and model contribute to surveying transportation, by **identifying vulnerabilities** and developing strategies to enhance security measures

Incentive

- The model enables *what if* analysis, allowing for the development of proactive policies, regulations, and risk mitigation strategies of the NFC, **strengthening security measures**, and informing decision-making in the global energy landscape

Dynamics

- The geographic network analysis and model sheds light on the dynamics and interactions within the NFC, providing valuable insights into **relationships** between countries involved

Leverage

- Geographic network analysis and modeling, we can ensure the responsible and **sustainable utilization** of nuclear resources

U.S. DEPARTMENT OF ENERGY
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