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Visualizing Safeguards:
Software for Conceptualizing and Communicating Safeguards Data

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Visualizing Safeguards:
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Abstract

The nuclear programs of states are complex and varied, comprising a wide range of fuel cycles and facilities. Also varied are the types and terms of states' safeguards agreements with the IAEA, each placing different limits on the inspectorate's access to these facilities. Such nuances make it difficult to draw policy significance from the ground-level nuclear activities of states, or to attribute ground-level outcomes to the implementation of specific policies or initiatives. While acquiring a firm understanding of these relationships is critical to evaluating and formulating effective policy, doing so requires collecting and synthesizing large bodies of information. Maintaining a comprehensive working knowledge of the facilities comprising even a single state's nuclear program poses a challenge, yet marrying this information with relevant safeguards and verification information is more challenging still. To facilitate this task, Brookhaven National Laboratory has developed a means of capturing the development, operation, and safeguards history of all the facilities comprising a state's nuclear program in a single graphic. The resulting visualization offers a useful reference tool to policymakers and analysts alike, providing a chronology of states' nuclear development and an easily digestible history of verification activities across their fuel cycles.

Introduction

Sound decision-making relies on timely access to relevant information. Yet for nonproliferation policymakers, acquiring and retaining this information is challenging for two reasons. First, the nuclear programs of states are complex and diverse, comprising a wide range of facilities and activities. Moreover, the status of these facilities and activities vary month to month across states with active fuel cycles. As relatively small changes to a state's nuclear program might bear significant proliferation impacts, policymakers are faced with the task of acquiring and maintaining a working knowledge of an enormous body of technical information. Second, the safeguards agreements of states also vary, each specifying the terms by which the inspectorate conducts verification activities across their fuel cycles. While knowledge of these agreements is critical to defining states' legal obligations, effective policymaking requires further knowledge of each state's history of compliance and interactions with the IAEA.

This complex and dynamic policy landscape presents a challenge to analysts and decision makers alike, making it difficult, either, to interpret the significance of ground-level developments across states' nuclear programs, or to associate these developments with the implementation of specific policies and initiatives. With the objective of shedding light on these relationships, Brookhaven National Laboratory has developed a visual framework for cataloguing, analyzing and communicating safeguards information. Delivered as a series of country-specific graphics and hosted on an interactive software platform, this system gives users the ability to merge the history of safeguards implementation across the entirety of a state's nuclear program with the construction and operational history of each facility in its fuel cycle. Once developed, layered metadata will allow users to zoom in on notable

safeguards events in the lifetime of each facility, learn what verification activities have uncovered, and access links to relevant documents and resources.

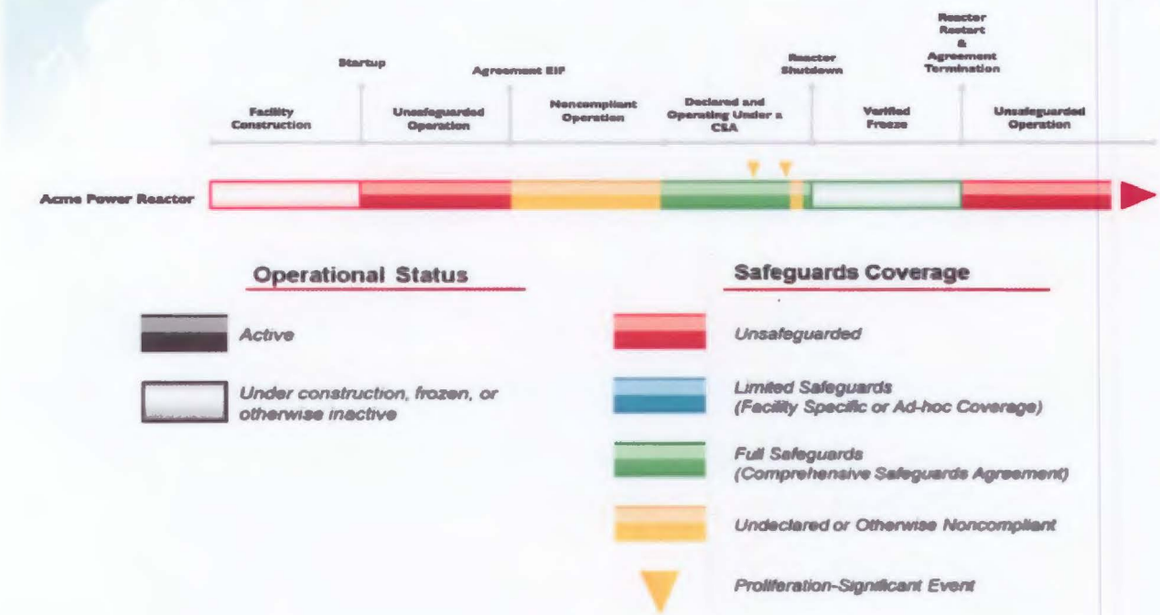

Figure 1

Visualizing Safeguards at the Facility Level

The graphic representation of a fictitious power reactor displayed above (Fig. 1) illustrates a simple yet powerful color and shape coding method for capturing facility-specific information. The operational status of the facility is simply represented by a bar that is either filled (active) or unfilled (inactive) over a given period of time, represented by its length. Unfilled boxes may have a variety of explanations: a facility may be under construction, in cold shut down, or frozen under the terms of a treaty or agreement. While these details are not explicitly communicated, it is often the case that they can be inferred from contextual information presented in the graphic.

The safeguards history of the facility, meanwhile, is reflected by its color. Red represents a lack of any safeguards obligations or coverage; blue, coverage under a facility-specific or ad-hoc agreement; green, coverage under an INFCIRC/153 – modeled Comprehensive Safeguards Agreement (CSA); and orange, a period of noncompliance—meaning the facility was either not declared to the IAEA or was being operated by the state in a manner that violated the terms of its safeguards agreement.

Together, these basic shape and color components can be translated into a useful narrative. Using the illustration provided above, we can determine when the reactor was constructed, how long it took to construct, and when it went critical. We can see that after a period of unsafeguarded operation, the host state likely entered into a safeguards agreement in bad faith. We can also see that after a long period of noncompliant operation the facility was eventually brought into accordance with the terms of a

Comprehensive Safeguards Agreement (CSA), and that two verification incidents and a brief period of noncompliance ended with a verified shutdown of the reactor and a long verified freeze. Finally, we know that the host state subsequently withdrew from its safeguards agreement and restarted the reactor, which operates unsafeguarded to this day.

Visualizing the Fuel Cycle

Building on this basic template, we can capture a country's entire fuel cycle in a single, panoptic graphic. For demonstrative purposes, open-source information relating to the safeguards and operational history of North Korea's nuclear program is presented below (Fig 2).[1] Each facility with a significant material presence or throughput in the country has been included.

Clearly, mapping all the facilities in a fuel cycle gives us much more information. One can trace the full history of facility constructions in the country, from the Yongbyon Radiochemistry Research Institute in the late 1950s at the top of the page, down to the 25Mw experimental light water reactor under construction today at the bottom.

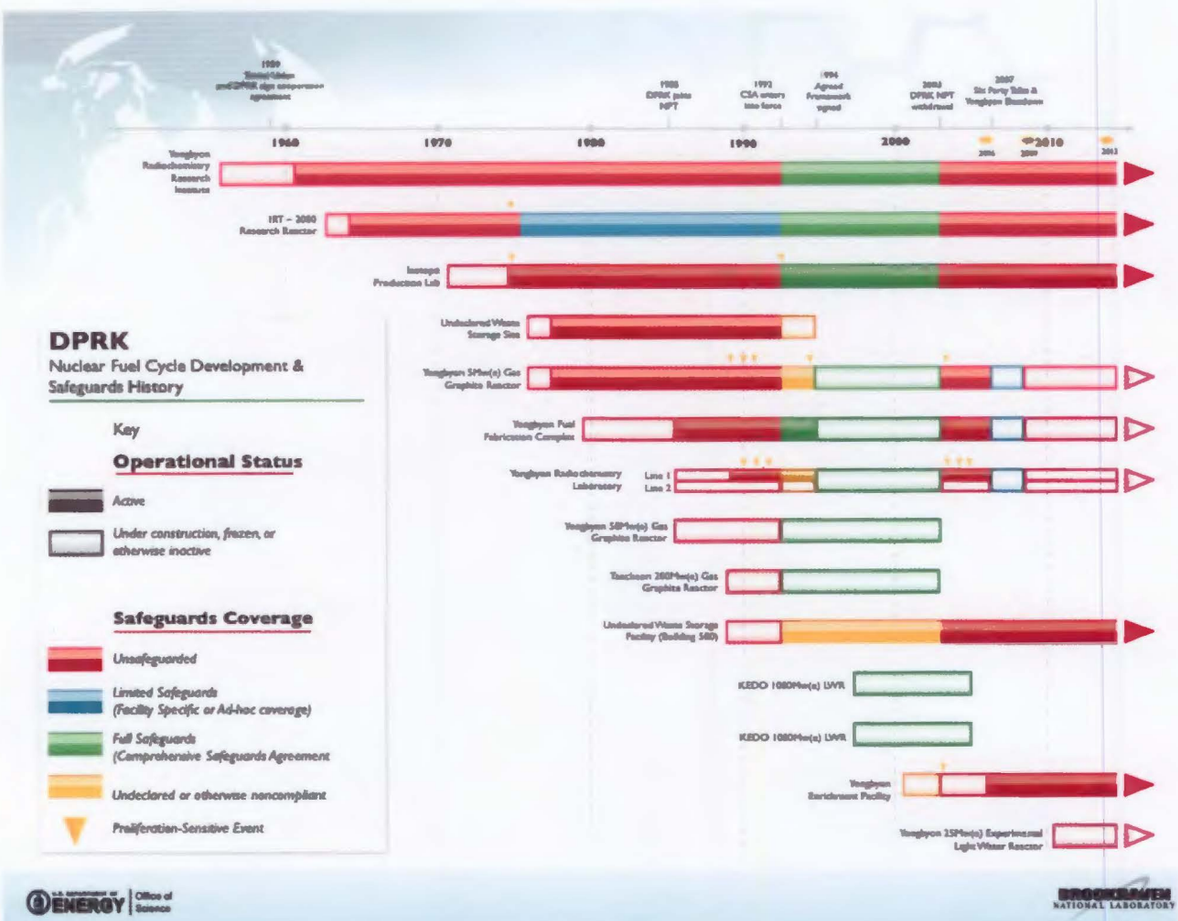

Figure 2

While this static view might serve as a useful general reference tool, it also provides important context for interpreting events at individual facilities. For instance, valuable insights might be gained by correlating major events on the timeline at the top of the graphic with the information presented in the facility timelines beneath it.

Isolating the first North Korean nuclear crisis to the years between 1992 and 1994, spanning from the entry into force of the country's CSA to the signing of the Agreed Framework, one can easily identify specific developments, at specific facilities, responsible for precipitating the crisis (Fig 3[a]). The proliferation significance of the seven-year delay between North Korea's accession to the Nonproliferation Treaty (NPT) and the entry into force of its safeguards agreement is also communicated to greater effect when viewed alongside the weapons-related activities known to have taken place over the same period.

Looking to the years after the crisis, we can also get a strong sense of how North Korea's plutonium production efforts were impacted by the terms of the Agreed Framework. We can see that the back end of North Korea's nuclear program was effectively frozen—with activities suspended at the 5Mw gas graphite reactor, fuel fabrication complex, and radiochemistry laboratory (Fig 3[b]). More than that, however, we can see what facilities and activities were omitted from the bilateral agreement—namely the long suspected undeclared waste storage facility known as building 500, and the undeclared construction of a gas centrifuge uranium enrichment facility at the Yongbyon complex.

In light of the context, one can almost go so far as to infer the latter facility's role in the agreement's collapse and the country's withdrawal from the NPT in 2003. Once again, direct connections can be drawn between events at specific facilities and the ensuing, second, North Korean nuclear crisis, culminating in the country's first nuclear weapons test, in 2006 (Fig 3[c]).

This visual format also presents opportunities to draw new insights from verification and facility-related information. Interesting to note about disablement activities conducted pursuant to the terms of the six party talks, for example, was their evident lasting effect on the country's plutonium production capabilities for several

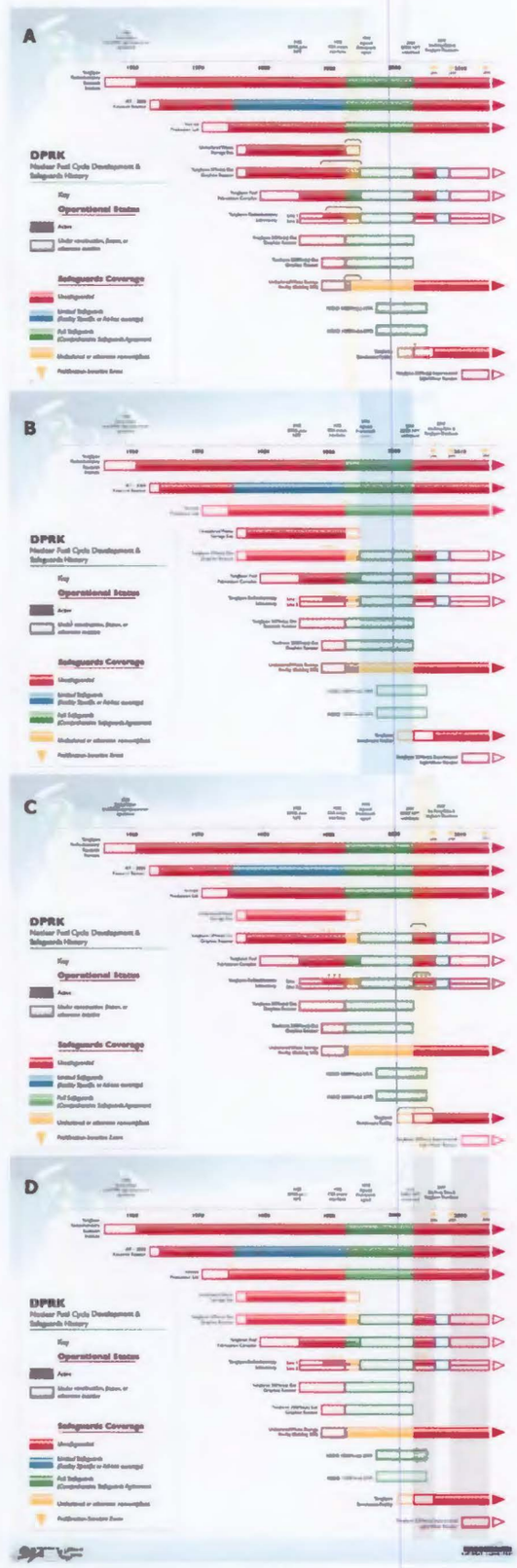

Figure 3

years after that agreement's collapse (Fig 3[d]). And while this fact is overshadowed by two weapons tests performed over the same period, it nonetheless produces a visible contrast to the effects of the Agreed Framework, which facility operators were able to reverse from the moment of North Korea's withdrawal in 2003.

Drill-Down Capability

The previously described graphic represents what will ultimately be the software application's home screen, where users will begin their analysis. However, of equal importance is the user's ability to "zoom-in" on facility information, to see the details of each proliferation significant event, and the date and nature of IAEA verification activities that yielded the Agency's conclusions.

This capability is demonstrated in graphic below, in which the user's view has been limited to North Korea's reprocessing facility between the years of 1989 and 1994. In the center of the right-hand pane, one can see that two clandestine reprocessing campaigns were carried out in 1989 and 1991 producing undeclared fissile material, and that additional undeclared material was extracted from a third, declared campaign, in 1990.[ii] Yet further information about these events is also accessible, including the sampling and analytic methods used by the Agency to arrive at these conclusions.

In this case, users can see that the Agency's findings were, at least in part, drawn from swipe samples taken from hot cells at the end of reprocessing line 1, and that separation activities involving material from three separate reactor campaigns were judged to have taken place at the facility based on varying proportions of Americium-241 found in the samples.[iii] In the same manner, information relating to significant events further along the facility timeline will also be supported, with many additional options for the inclusion of hyperlinked resources and mixed media attachments.

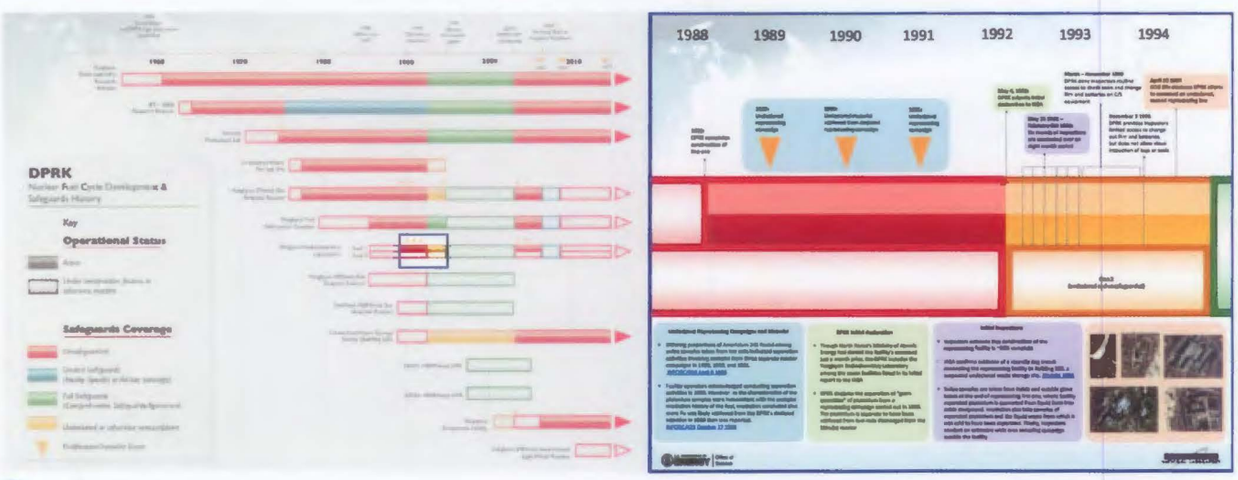

Figure 4

Once developed, this software will offer a useful reference tool to policymakers and analysts alike, providing a chronology of states' nuclear development and an easily digestible history of verification activities across their fuel cycles. Beyond helping both groups visualize the link between safeguards policy and implementation, this interactive visualization will serve the following additional purposes:

- **Modeling** – enabling the identification of trends across data sets, as well as the projection of state behaviors, policy outcomes, breakout scenarios and future fuel cycle development
- **Professional Training** – Providing an engaging teaching tool to students and educators of safeguards and nonproliferation policy
- **Data Archiving** – Providing an intuitive platform on which to organize and access information (depending on the user, this platform might be tailored to host classified intelligence [IC], restricted-distribution safeguards data [IAEA, DOE, foreign governments], or open-source information [students, educators, NGOs]
- **IAEA Communication** – Enhancing the effectiveness of Agency communication, both to internal and external audiences, by providing a clear means of anchoring concerns and conclusions to information gleaned from specific verification activities.

Future Work

The work conducted to date has been accomplished through BNL internal resources for concept development and the assistance of interns funded by the Next Generation Safeguards Initiative. BNL hopes to partner with one or more U.S. government entities to develop a pilot software application based on the visual template described above. Depending on customer needs, options to include additional information, such as nuclear material types, flows and volumes, may also be integrated.

A video demonstration, including a simulation of the software's anticipated capabilities, can be accessed here: https://www.dropbox.com/s/kppoyv8t5yrzi0q/DataVisVideo-finished.wmv?dl=0

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[i] This graphic is out of date, has been developed for demonstrative purposes only. As such, it may include minor errors or omissions. The Yongbyon 5Mw gas graphite plutonium production reactor, for example, was restarted in September 2013.
[ii] INFCIRC/419 Director General's Report to the Board of Governors. 8 April 1993
[iii] Albright, David. "North Korean Plutonium Production" via: http://scienceandglobalsecurity.org/archive/sgs05albright.pdf