Mitigating Low-Enriched Uranium Transportation Network Risk

Background

In the United States, shipment risk of nuclear fuel from processing centers to nuclear reactors is generally not a factor in determining which supplier a nuclear power plant uses. The lack of shipping risk is a potentially significant problem because the production of nuclear fuel need not serve peaceful, power-generating purposes. The fissile material required to fuel a power-generating nuclear reactor is generally low-enriched uranium (LEU) processed to around 3% U235 concentration. It is not enough to create a nuclear blast, which would require highly enriched uranium (HEU) processed to at least 90% U235 concentration. However, LEU can be used to create a radiological dispersal device (RDD), or can be combined with conventional explosives to create a 'dirty bomb.' RDDs and 'dirty bombs' have the potential to disperse radioactive material over a wide area, contaminating landscapes, people, and infrastructure. Deaths directly attributable to radiological poisoning would be low, but a dirty bomb/ or RDD can exact high costs in area denial, economic disruption, decontamination costs and resources, and psychological trauma.[1]

Intentional misuse of nuclear material is not the only potential hazard. Numerous radiological accidents and incidents have been recorded ever since Eben M Myers, amateur golfer and professional industrialist, died in 1932 of massive radiological poisoning from long term ingestion of Radithor, a radium based 'medicine.'[2] To this day, the papers and personal effects of Madame Marie Currie are considered unsafe to handle without protection due to the massive exposure to radioactivity during her career.[3] Whenever humans and human environments are exposed to radioactive material there is a potential for tragedy. Any system or network involving radioactive material must incorporate analysis of risk reduction.

Modeling

The shipment risk of fissile material can be analyzed in many ways: personnel risks, facility security, operational security, safety procedures, incident response protocols, etc. Shipping distance can be a good proxy for many of these factors, and is the component of shipment risk we analyze. For example, General Electric's fabrication facility in North Carolina currently supplies Columbia nuclear reactor in Washinton at a distance of 2,631 miles. Whereas, Areva's fabrication facility is only 11 miles from Columbia (figure 1). Reducing distance travelled offers far less opportunity for accidents en route and criminal hijacking, and increased control of route security and incident response. In modeling, we use the route distance between nuclear fuel fabrication facilities and nuclear power plants as a proxy for nuclear material shipment risk. In order to reduce risk in this context, we analyzed multiple scenarios with the objective of minimizing the distance traveled over a transportation network from the point of nuclear material fabrication to the nuclear power plants.

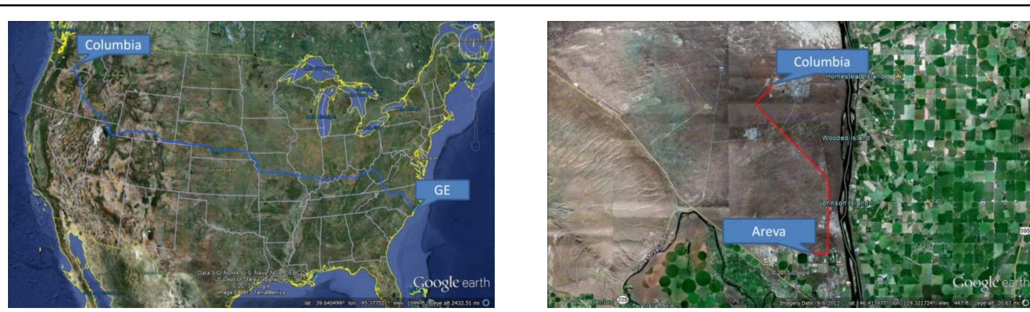

Figure 1: An example of how distance is not a primary factor in determining contracts. General Electric's fabrication facility supplies Columbia power plant by travelling across the country, however, Areva's fabrication facility is only 11 miles south of the plant.

This model also assumes that number of deliveries to a particular consumer per year is determined by the number of nuclear reactors at that site. For example, Beaver Valley has two reactors and requires two deliveries per year. Finally, the supply available from each producer is determined by current market share. Capacity at each fabrication facility far outweighs demand. However, in such a highly regulated industry, we are assuming market share remains fairly consistent based on size of producer and contract requirements. Our research estimates current market share as follows:

Company	% U.S. Market
Areva	35.0
General Electric	21.4
Westinghouse	43.6

Table 1: Current US market share of the three main US Nuclear Fuel Fabrication companies

Running the min-cost flow with these assumptions reduced total distance LEU travelled on US roadways per year from 145,579 miles under current contracting to 91,535 miles. This equates to a 37% reduction in total distance travelled. If world events resulted in increasing the risk of transporting LEU past some government/democratically defined threshold, it is viable that the government could step in and encourage or force producers to adjust delivery of LEU. After all, it is the responsibility of the US Nuclear Regulatory Commission to oversee security efforts on all nuclear fuel transportation.

Next we chose to model a scenario where terrorists were determined to hijack a LEU shipment. The assumption is that the longer each particular shipment was on the road, the more successful a terrorist was at capturing that shipment due to the fact that they had more time to interdict and more opportunity to pick a location of their choosing. In this model, we utilized a multi-commodity flow model in GAMS to reduce the longest route travelled for the entire network from producer to consumer while still maintaining current market share. The longest route was Areva to Braidwood. This reduced the longest distance from 2,879 miles to 1,977 miles, a reduction of 31% reduction.

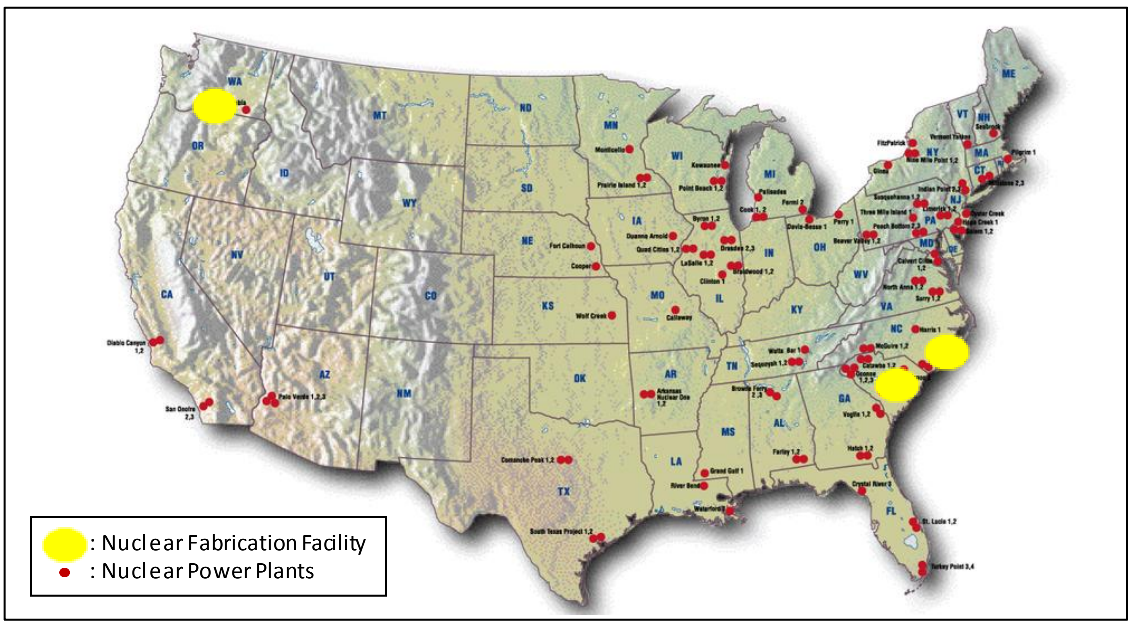

Figure 2: Location of US Nuclear Fuel Reactor and Fabrication Facilities. The three fabrication facilities connect to each reactor site via a directed edge. There are a total of 103 nuclear fuel reactors located at 61 actual nuclear power sites.

In addition to threats to LEU transport, if a combined attack were to be made at a nuclear fabrication facility it could have cascading effect. In this context, we analyzed the same model with the loss of each of the fabrication facilities. Results indicate that the loss of GE or Westinghouse do not affect the longest distance travelled. This is a fairly intuitive result given the close proximity of the two facilities, when one is attacked, the other facility can meet the demand. However, when Areva is attacked, the longest route travelled goes from 1,997 miles (with Areva) to 2,688 (w/o Areva). This suggests that security of facilities should be weighted towards Areva.

Finally, we looked at our future environment by taking into account projections of operable nuclear reactor sites in 2025. This increased number of deliveries from 103 to 126. We analyzed this new model both by attempting to minimize total distance traveled and by minimizing maximum route travelled using the same assumptions as above. Even with the new demand requirements, the total distance travelled on all routes was reduced from the current contract of 145,579 miles to 111,005 miles. When we minimized the longest route, it resulted in a decrease distance as with previous demand constraints of 2,879 miles to 1,965 miles (Areva to Dresden). The reason for this is because Areva can supply to the new demand points and meet its market share constraint without having to reach across the country as far. The majority of additional demand was due to current reactor sites expanding with new reactors, essentially forcing more flow on those edges. In fact, only four new consumer nodes were produced with this new demand but since they were located relatively east, close to GE and Westinghouse, they did not factor into the longest route.

Conclusion

Currently, LEU contracts to supply nuclear reactors do not consider the distance from fabricator to plant as a risk-mitigation component. Our analysis reveals changes that would be suggested if route distance were the primary (or indeed, the only factor) in considering risk mitigation. A more realistic solution of fabricator-power plant supply relationships would lie somewhere in between these two extremes. Reducing the distance traveled of LEU can have a generous impact on the security risk of the transportation operations and if incentivized properly, the major stakeholders can adopt this position as well. Power plant operators and LEU fabricators would likely realize cost savings in individual shipment operations, taking into consideration all cost factors, such as fuel, labor, and security costs. Government regulators would realize a risk reduction benefit, and can incentivize the private parties in the LEU market through licensing requirements, fines, penalties, and tax burden reduction for proper risk mitigation strategies. By its very nature, LEU must be strictly regulated, and demands regulatory scrutiny of all aspects of the market.

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[1] http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-dirty-bombs.html

[2] "Eben M. Byers: The Effect of Gamma Rays on Amateur Golf, Modern Medicine and the FDA," *Allegheny Cemetery Heritage,* Fall 2004

[3] Rollyson, Carl (2004). *Marie Curie: Honesty In Science*. iUniverse, prologue, x