George Zakka

[redacted]

December 11, 2018

Paymon Aliabadi
Executive Vice President and Chief Enterprise Risk Officer
Exelon Corporation
PO Box 805398
Chicago, IL 60680-5398

Re: Tackling the nuclear waste problem at the Limerick 1 and 2 generating stations

Dear Mr. Aliabadi,

I would like to thank you for attending my oral presentation on how Exelon can reduce the risk of a nuclear accident. This is the complete version of my project proposal which I have sent to you given that you are in charge of assessing and mitigating risk at Exelon nuclear generating stations. You should find my proposal particularly interesting because I discuss how the NRC's previous decision allowing for the storage of spent fuel rods in denser and denser configurations failed to take into account important information. I believe this will cause you to reconsider Exelon's decision to leave the majority of spent fuel rods in spent fuel pools.

As I stated in my initial correspondence to you, I am writing to inform you that the current storage configuration of spent fuel rods at the Limerick Generating Stations 1 and 2 present a grave risk to the surrounding population as well as to the investments of Exelon's shareholders. My goal is to convince you that action must be taken to store the accumulated spent fuel in a manner that minimizes the risk of catastrophe without significantly affecting operating costs. Specifically, I am calling on you to move all spent fuel rods that have cooled for at least 5 years to dry cask storage. Dry cask storage is a very secure way of storing spent fuel rods and is resilient to leaks, physical impact, and absorbs radiation to protect workers.

I assure you that the information I will be giving you in this correspondence will be worth your time, in spite of it being in very short supply. After going through my proposal, I hope you will be convinced of the presence and severity of the problem with Exelon's current spent-fuel storage practices and be compelled to reach out to me by phone at [redacted] or by email at [redacted]

Sincerely,

George Zakka

Tackling the nuclear waste problem at the Limerick 1 and 2 generating stations

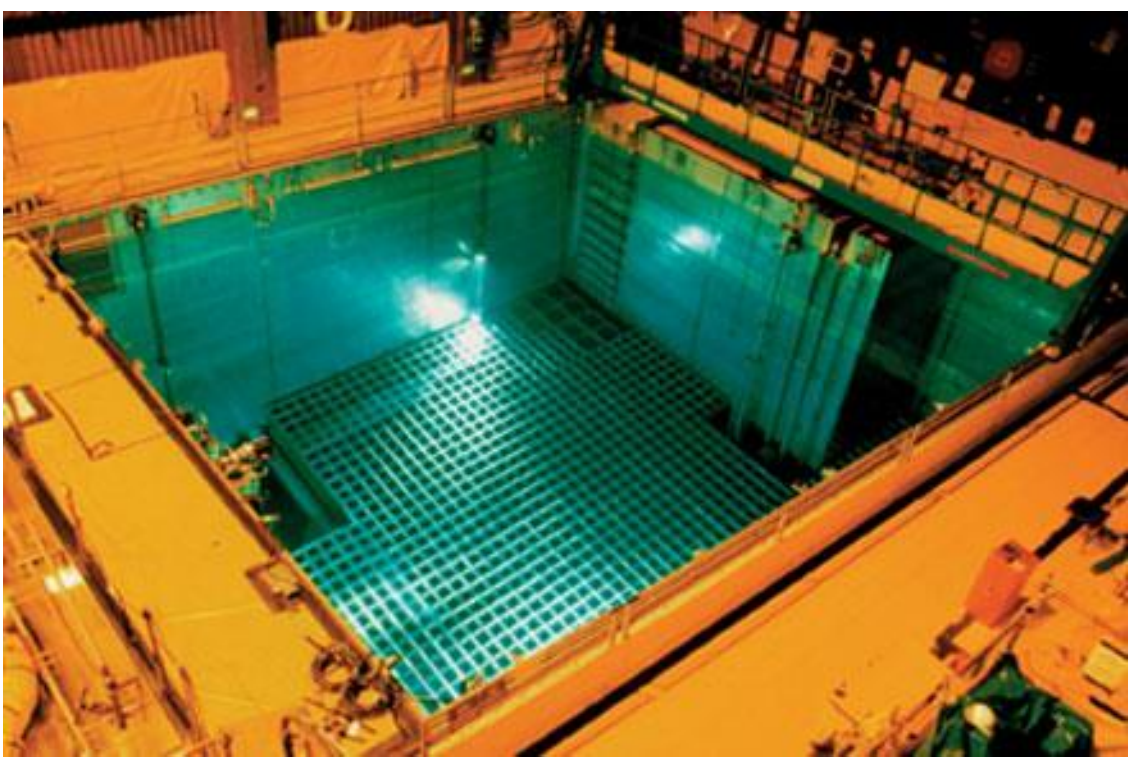
Submitted by: George Zakka

[redacted]

Submitted to: Mr. Paymon Aliabadi
Exelon Corporation
PO Box 805398
Chicago, IL 60680-5398

Submitted on:
December 11, 2018

Scientific and Technical Writing (355:302:14)
Dr. Michael Masiello



https://www.ucsusa.org/nuclear-power/nuclear-waste/safer-storage-of-spent-fuel#.XA_laWhKhPY

Abstract

The NRC currently allows nuclear generating stations to store spent fuel rods in dense configurations which raise the risk of accident in the event of loss of coolant or cooling ability. The author explains how this decision was made based on poor assumptions and a failure to consider important information. In addition, the potential consequences of these spent-fuel practices at Exelon's Limerick 1 and 2 generating stations, given the stations' close proximity to a densely populated metropolitan area, is laid out. Subsequently, past nuclear accidents at Chernobyl, Fukushima, and Three-Mile-Island, substantiating the author's claim that spent-fuel storage practices at the Limerick generating stations, are presented. Next, the solution to take all spent-fuel rods having cooled for at least 5 years and move them to dry-storage casks is examined in detail. This is followed by a plan to pay for this safety measure by very slightly raising the price of power and a walkthrough of the calculations showing how this change in price will be hardly noticed by Pennsylvania power consumers.

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Introduction

A Threat That Can't Be Ignored

As I am sure you know, spent nuclear fuel rods must be cooled in pools of water immediately after being discharged from reactors. Then, after cooling for several years, the rods can be moved to dry storage casks where they will continue to cool passively through natural air circulation. To minimize storage costs, fuel rods are packed in the pools as densely as possible and only when they reach the maximum allowed capacity are some rods moved to dry storage casks to make space. However, the Nuclear Regulatory Commission has set the maximum capacity to a quantity that is significantly beyond what most reactors were initially designed to hold. This is in spite of the fact that spent fuel pools were initially designed to store one or two reactors' worth of spent fuel because the spent fuel was, at the time, expected to be periodically removed and shipped out for reprocessing. Unfortunately, spent fuel accumulated because reprocessing of spent fuel never became commercially viable. This storage configuration presents significant danger as dense-packed fuel would be susceptible to catching fire if some terrorist attack or other accident caused a loss of the pool's cooling water. Such a catastrophe would begin when steam oxidizes a small amount of a fuel rod's zirconium cladding thus liberating sufficient hydrogen gas which can then easily combust, likely destroying the building housing the spent-fuel pools and exposing their radioactive contents to the environment and surrounding population. In addition, the NRC allows spent fuel to remain in pool storage until a permanent spent fuel repository is established (Schoeppner 2017). However, the U.S. has been trying to establish such a repository for decades and there is no reason to suspect their odds of success will increase as time goes on (Reuters 2011). Therefore, waiting for a permanent repository is a useless risk to the plant and surrounding population.

How We Got Here

The NRC considered whether to force nuclear power plants to transfer fuel that had cooled for over 5 years to dry storage but decided not to, based on their calculation of the probability of a spent fuel fire and its estimated cost to the public. However, the NRC admits there being a large uncertainty in the estimated probability. In addition, it did not account for the possibility of a terrorist attack and in its calculations assumed all relocated people would be able to return home within less than a year which is inconsistent with the experience of Japan following the Fukushima incident. Furthermore, the dose of radiation it deemed to be acceptable for the public to possibly be exposed to was greater than that recommended by the EPA and even Soviet authorities after Chernobyl. Finally, the NRC failed to account for "societal risk" or the risk of land becoming uninhabitable, psychological trauma, and lost economic productivity. Therefore, for these reasons it is believed the NRC adjusted the input parameters of its cost-benefit analysis to justify its decision rather than use realistic parameters to inform it (Schoeppner 2017).

The Risk to the Public

Montgomery county, where Limerick, PA lies, is home to over 800000 people. It is less than 25 miles away from Philadelphia, where over 1.5 million reside (U.S. Census Bureau 2017). In April of 1986, an accident at the Chernobyl nuclear power plant near the now abandoned town of Pripyat, Ukraine released large amounts of radioactive material in the environment that resulted in hundreds of thousands of people being evacuated from their homes. The Chernobyl incident is considered the worst accident in the history of nuclear power. It resulted in over 700 square kilometers of land being contaminated by over 100 Ci of radiation. However, the amount of radioactive material in the Limerick reactors is almost 10 times greater than the amount at the Chernobyl reactor. An incident at a spent fuel pool with less spent fuel than that at Limerick could result in the release of over 1000 Ci to an area 180 to 6000 square kilometers wide depending on wind flow and other factors. It is important to note that exposure to 100 Ci over 10 years increases cancer risk by about 1% whereas exposure to 1000 Ci over the same period increases risk by 10%. This amounts to hundreds of thousands of additional cancer cases given the population density of the area surrounding the Limerick reactor (Alvarez 2003).

Figure 1: Aftermath of Chernobyl Incident

Source: Vice News

Learning from the Past: Fukushima

As mentioned earlier, in the event of a loss of the cooling pool's water, densely packed fuel rods would be susceptible to catching fire following the release of combustible hydrogen gas (Schoeppner 2017). This exactly what happened at the

Figure 2: Spent-Fuel Fire at Fukushima Daichii Reactor

Source: The Telegraph

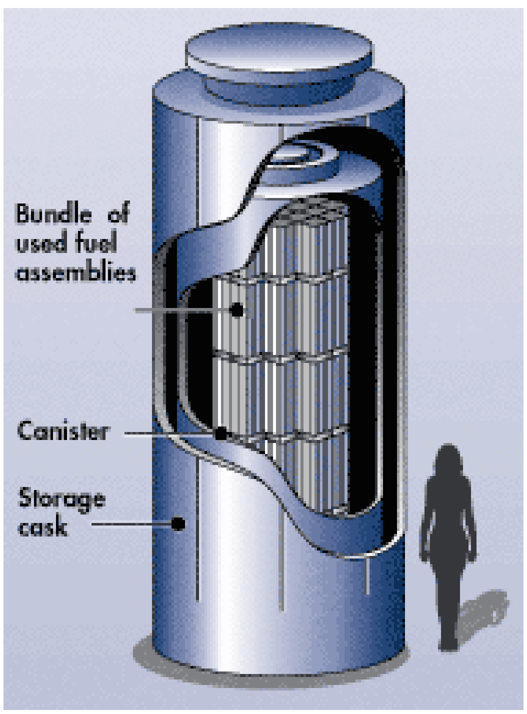
Fukushima Daiichi plant in northern Japan in March of 2011. In addition, the rods themselves actually melted due to the loss of cooling and bored large holes in the floor of the reactor vessels. This exposed the nuclear materials of the reactor cores and contributed to the release of radiation which resulted in the relocation of over 50000 Japanese civilians and billions in damages and cleanup efforts. Although, this incident did not involve spent fuel rods, but unspent fuel rods in the reactor core, it does show us the possibility of the release of hydrogen gas from oxidized fuel rod cladding and loss of cooling to critical reactor components (E.B. 2018).

Learning from the Past: Three-Mile Island

The Three Mile Island generating station near Harrisburg Pennsylvania was the site of one of the worst commercial nuclear power accidents in the United States. In 1979, reactor cooling was interrupted by a mechanical or electrical failure of water pumps. However, control room instruments did not detect the failure and the result was a meltdown of half the reactor's core (Jacobo 2017). This is another example of the dangers and inevitability of the loss of cooling systems and how steps must be taken to mitigate potential damages.

LITERATURE REVIEW

Figure 3: Generic Dry Storage Cannister



Source: NRC

The Benefits of Dry-Cask Storage

Dry cask storage involves taking spent fuel rods that have been cooled for at least 5 years, storing them in a steel cylinder filled with an inert gas that is welded or bolted shut, and then surrounding it with additional layers of steel, concrete, or other materials to provide additional radiation shielding to workers and the public (U.S. NRC 2017). Given how disastrous the loss of coolant in a nuclear generating station's cooling system can be, it is obvious why a cooling system which does not require coolant has significant security advantages. This is the case with dry cask storage. Casks manage the heat release of spent-fuel rods, ensuring they give off heat gradually, which results in them releasing as much heat as the average home heating system. This means there is no need for fans or pumps to cool them down. Only natural air circulation is required (U.S. NRC 2016). There are several other advantages of dry casks over spent fuel pools. First, in the event of an accident, less fuel will be at risk because an incident at a dry cask storage facility would likely affect at most a few casks and a few metric tons of spent fuel at risk. This is in contrast to an incident at a spent fuel pool which would put hundreds of metric tons of spent fuel at risk. This is mainly because spent fuel in a dry cask storage system is made of independent modules and the fuel is significantly more dispersed, so any failure of one cask or subsystem will not spread and compromise the entire system. Second, fuel stored in dry casks has the advantage of not being prone to the zirconium cladding fires mentioned earlier or to fires resulting from the combustion of hydrogen gas produced from the oxidation of zirconium cladding by water vapor. Either of these incidents could result in the release of radioactive aerosols that may be spread by wind and travel great distances. Lastly, breaches in a dry cask may be repaired easily by plugging it with radiation absorbing material until the casks can be permanently fixed or replaced, whereas breaches in spent fuel pools may be much more difficult, especially if intense radiation or building collapse prevented workers from reaching the pool (NAS 2006). Furthermore, they free up space in spent fuel pools for rods that have more recently exited the reactor core and are significantly hotter and more radioactive rods that have been in pools for even a few months (U.S. NRC 2017). Finally, casks absorbs radiation emitted by the fuel rods which protects workers, prevent nuclear fusion from occurring in the rods, are resistant to tornados, floods, earthquakes, extreme temperature, and other extreme scenarios (U.S. NRC 2016).

Licensing of Dry-Storage Casks

The NRC has developed a set of requirements for dry-storage casks to ensure they provide adequate protection of public health and safety, the environment, and plant workers. In addition, nuclear plants can obtain 2 types of licenses which allow them to store spent fuel rods in dry storage. The first is a site-specific license which allows a specific cask design to be used at a specific location and offers the opportunity for a hearing before the NRC grants the license. The second is a general license which permits a reactor site to use any cask certified by the NRC assuming the site meets the specified conditions in the certificate (U.S. NRC 2016). However, the Limerick generating stations already have a general license, so no additional applications are required (Exelon Corp n.d.).

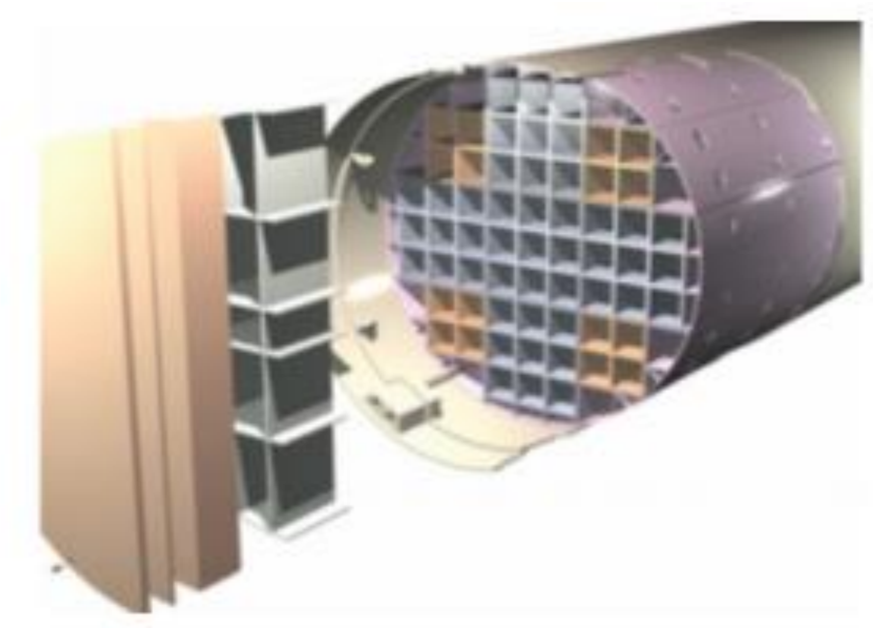
NRC Safety Standards for Dry-Storage Casks

Title 10 of NRC regulations § 72.236 lays out the following general requirements for an acceptable dry-storage cask design. The requirements are numerous, so I will only go over the smallest number I believe will help to convince you they are a safe alternative to spent fuel pools. First is radiation shielding and confinement. An acceptable cask should, during normal operations and anticipated occurrences, not provide a dose of radiation to anyone beyond the controlled area (non-plant works/civilians) exceeding 25 millirem per year to the whole body, 75 millirem per year to the thyroid, or 25 millirem per year to any other critical organ (U.S. NRC 2017). To put this into perspective, 1 millirem is the equivalent to an average year of watching TV. In addition, the average U.S. resident is exposed to 45 mrem per year from cosmic rays and 70 mrem per year from diagnostic x-rays (GSU n.d.). Second, an acceptable cask will be designed to provide redundant sealing of confinement systems to reduce the chance of leaks and ensure the spent fuel rods are isolated from the outside environment. Lastly, the cask will provide adequate heat removal capacity without active cooling systems such as fans or pumps while maintaining structural integrity and proper isolation of the radioactive contents (U.S. NRC 2017).

A Proven Dry Storage Solution

A great choice for the dry-cask storage system would be the NUHOMS 61BTH Dry Shielded Canister which is compatible with the standard OS197 cask (Transnuclear Inc 2011) which can store up to 61 spent fuel assemblies. There are already 8 in service at the Limerick generating station's independent spent fuel storage site that have been providing dependable spent fuel storage since 2015 (Exelon Corp 2015). In addition, as of 2015, a total of 576 of these systems have been deployed to store a total of 22,846 spent fuel assemblies. The longest any of these systems has been deployed is 10 years and the only failure has been the result of a blocked air duct which resulted in temporary overheating (U.S. DOE 2015). After Holtec International's HI-STORM 100 cannister system the NUHOMS 61BTH has one of the best records in terms of rate of failure or malfunction (U.S. DOE 2015).

Figure 4: The NUHOMS 61BTH DSC



Source: Transnuclear Inc

More on the NUHMOS 61BTH

The 61BTH is licensed to store and transport 61 boiling water reactor fuel assemblies, including assemblies that have been damaged. The 61BTH has the added benefit of being transported and loaded from spent fuel pools by a fully shielded transfer cask that provides enhanced radiation protection for workers. It consists of tubular fuel compartments of varying sizes to ensure maximum area of contact between the inner cannister and outer cask and maximize transfer of heat from the rods to the cask and thus minimizing the temperature of the rods (Transnuclear Inc 2011).

PLAN

Overview

Moving sufficiently cooled spent fuel rods to dry casks is a fairly simple process and the NRC has determined that the risks of loading and storing spent fuel in storage casks is minimal (NRC 2016). First, the steel cannisters are placed in the cooling pools where the spent fuel rods will be placed inside them. Then, the cannister is removed and all water and air are removed from it. Next, the cannister is filled with inert gas, welded shut, and thoroughly tested for leaks. Finally, the cannister is placed in the cask and the entire assembly is moved to either an onsite or independent fuel storage facility (U.S. NRC 2017). The casks would be stored at the Limerick reactors' onsite independent spent fuel storage installation (ISFSI) (U.S. NRC 2018).

The First Step

To begin the process of loading sufficiently cooled spent fuel rods to dry storage, you will need to get in contact with Chris Miller, the VP of Sales and Marketing for Transnuclear Inc, by phone at 410-910-6924. From there, Mr. Miller will send a team to analyze the reactor site and create a site-specific "pool to pad" procedure, outlining exactly how the rods will be moved from the spent fuel pool to their new home inside dry storage casks on the outdoor concrete pad of Limerick's ISFSI. Fortunately, Transnuclear will take care of almost all the dirty work of loading the used fuel from the pool into the cannisters, performing inspection, confirmation, and documentation of the fuel loading process, placing the dry storage canister in a temporary transfer cask and placing the lid to seal the cask, welding the cannister shut, filling it with helium as well as checking for leaks, vacuum drying the cannister, transporting it to the ISFSI and then to the horizontal storage module, post-loading decontamination services, completing all the necessary documentation required by NRC regulations, and finally preparation and storage of ancillary equipment (cranes, trucks, transfer cask, etc.) for the next spent fuel transfer. In addition, Transnuclear has the capacity to train plant workers to correctly handle and inspect the NUHOMS system to simplify long term use (Transnuclear Inc).

BUDGET

Nuclear Power is Still a Business

In this section I will walk you through my calculations for the cost of transferring the spent fuel from wet to dry storage. As was mentioned earlier, nuclear experts agree all spent fuel that has cooled for at least 5 years in wet storage should be moved to dry storage due to its significant security advantages (Alvarez 2011). The Limerick 1 and 2 reactors together, as of 2011, have 1149 metric tons of heavy metals (MTHM) in wet storage and 359 MTHM in dry storage at its ISFSI (U.S. NRC 2018) . All 1149 MTHM of spent fuel in wet storage since 2011 plus the additional 53.7 MTHM added in 2013 has cooled for at least 5 years and should be moved to dry storage (Alvarez 2011). The 53.7 MTHM figure is an estimate based on the fact that the average Mark II GE Type 4 boiling water reactor has 764 fuel assemblies per reactor core with each assembly weighing 281 kg, spent fuel rods comprising approximately one quarter of that weight, there being 2 operating reactor cores, and 1000 kg in a metric ton (Buongiorno 2010).

$$(1)\quad 764\ \frac{assembly}{core} \times 281\ \frac{kg}{assembly} \times \frac{1}{4} \times 2\ cores \times \frac{1\ metric\ ton}{1000\ kg}$$

$$= 53.7\ metric\ tons\ (MT)$$

Therefore, in total 1202.7 MTHM must be transferred. The total price of the transfer will be $421 million given that Exelon Corp has reported paying $1 million for each NOHOMS 61BTH cannister and OS197 cask and $0.5 million for the transfer of the fuel assemblies (Wald 2011).

The calculation is as follows:

$$(2)\quad \frac{1202.7\ MTHM}{0.07025\ \frac{MTHM}{assembly} \times 61\ \frac{assembly}{cannister}} \times 1500000\ \frac{dollar}{cannister} = 421\ million\ dollars$$

While this may seem like a large figure, it can actually be retrieved over 4 years from consumers by raising the price of electricity by 0.005 dollars per kWh and with them only paying an average of 5 dollars extra per month on their electric bill. In return they would be better protected against disaster and the risk to Exelon's assets would be reduced. The 5 dollars per month figure was arrived at using the fact that on average Pennsylvanians use about 10402 kWh of power per year and pay 1300 dollars per year on their electric bill, making them pay about 0.125 dollars per kWh (U.S. EIA 2009). In addition, the combined power output of the Limerick 1 and 2 reactors is roughly 19,395,369,000 per year (Exelon Corp n.d.). Therefore:

$$(3)\quad \frac{10402\ \frac{kWh}{year}}{1300\ \frac{dollar}{year}} = 0.125\ \frac{dollar}{kWh}$$

$$(4)\quad \frac{421{,}000{,}000\ dollar}{4\ years\ \times 19{,}395{,}369{,}000\ kWh} = 0.005\ dollar$$

$$(5)\quad 12\ months\ \times\ (0.125\ dollar + 0.005\ dollar)\ \times 10402\ kWh$$
$$= 1357\ dollar$$

$$(6) \quad \frac{1357\, dollar - 1300\, dollar}{12\, months} = 5\, \frac{dollar}{month}$$

Another justification for this expense is the fact that in the event of an accident, the price of relocating the public, repairing nuclear facilities, and radioactive cleanup would be enormous. In addition, nuclear plant owners would be liable to pay up to 13.6 billion in damages to public property (NAS 2016). The cost of minimizing spent fuel accidents is but a small fraction of this 13.6-billion-dollar figure. I hope that I have convinced you that the current state of spent fuel storage at the Limerick 1 and 2 reactors and all across the country needs to be addressed immediately. In addition, I hope that I have made the case that remedying the situation is both very doable and a requires only a small fraction of that which could be incurred should an accident take place. I would be more than happy to meet you in person to elaborate on the issue and my plans to solve it as well as any questions or concerns you have.

DISCUSSION

In order to reduce the risk of accident at the Limerick 1 and 2's spent fuel pools following a loss of coolant incident, all spent fuel rods having spent over 5 years cooling in spent fuel pools should be moved to dry cask storage immediately. Past incidents at the Fukushima, Three-Mile-Island, and Chernobyl plants shows that loss of coolant incidents are a possibility that need to be accounted for. The consequences for failing to properly prepare can range from a small radiation leak into the environment to the rendering of hundreds of square miles temporarily uninhabitable and causing significant public panic. Reducing the density of spent fuel rods at spent fuel pools reduces the risk such incidents and others. Purchasing 281 additional NUHOMS 61BTH cannisters over 4 years from Transnuclear Inc is the proper solution. In addition to be a well-tested and reliable model of cannister, the cost is reasonable and can be paid off over 4 years through a miniscule increase in electricity prices. Furthermore, in the unlikely event that a permanent storage site in the U.S. is established, the process of moving all spent fuel rods in wet storage can be halted, with the full cost of the transfer not having to be incurred, and with minimal loss of investment because to transfer the spent fuel rods to the permanent repository, they must be placed in transfer cannisters which the NUHOMS 61BTH is licensed to act as. By taking these preventative measures, Exelon demonstrates itself to be leading the fight to ensure public health and safety in a time of great mistrust of large corporations and helps to ease movements to have current and future nuclear plants shutdown.

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