Nuclear Reactor Fuels, Spent Nuclear Fuel, Storage, and Transportation

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Topics

- Who We Are/History
- Current and Potential Future Nuclear Fuels
- Spent Fuel Storage Overview
  - Governing regulations
  - Safety and security review; design elements
  - Cask and storage system types/manufacturers
- Transportation of radioactive materials (RAMs)/spent nuclear fuel (SNF)
  - Security elements
  - Package testing

Who We Are & History…


Chairman David A. Wright


Commissioner Annie Caputo


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Commissioner Bradley R. Crowell


Commissioner Matthew J. Marzano

An independent federal agency, led by five Presidentially-appointed, and Senate-confirmed, Commissioners.

The NRC employs ~2800 people among its suburban Maryland headquarters and four regional offices in Pennsylvania, Georgia, Illinois and Texas.

History:

- Atomic Energy Commission
  - Atomic Energy Act of 1954
- Energy Re-organization Act of 1974:
  - Established Nuclear Regulatory Commission (Regulatory Role)
  - Plus, separate agency that came to be known as the Department of Energy (Developmental and Promotional Role)

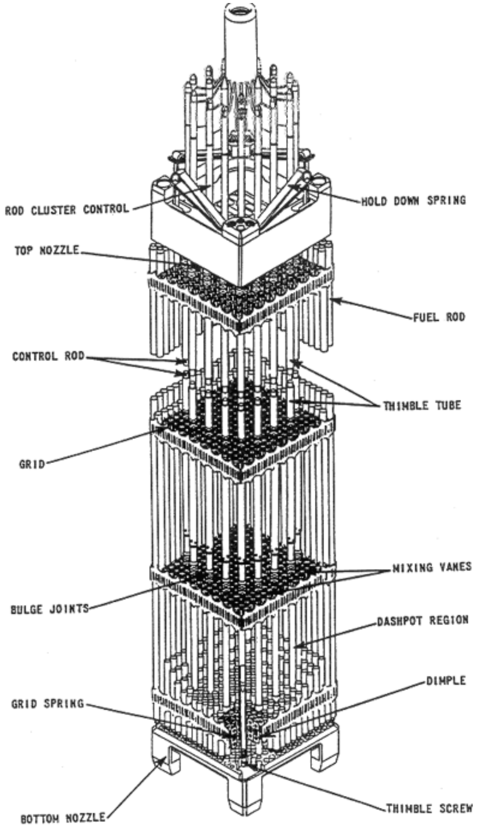
NRC Mission Statement – Protecting People and the Environment

The NRC protects public health and safety and advances the nation’s common defense and security by enabling the safe and secure use and deployment of civilian nuclear energy technologies and radioactive materials through efficient and reliable licensing, oversight, and regulation for the benefit of society and the environment.

Current and Potential Future Nuclear Fuels

Current Fleet Uranium Fuels

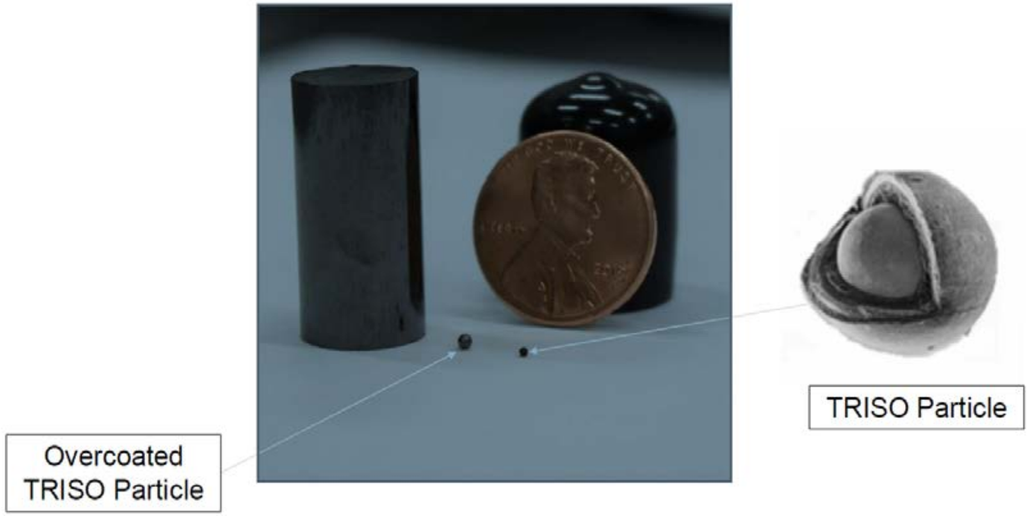
Uranium dioxide fuel pellets
- Currently up to 5% U-235
- Planning for higher enrichment



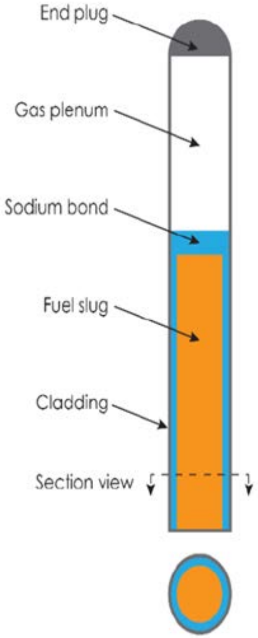
Reactor Fuel Assembly

Zirconium alloy cladding tubes
- Planning for coated cladding (chromium-based coating)

Potential Future Nuclear Fuels



TRISO fuel



Metallic fuel

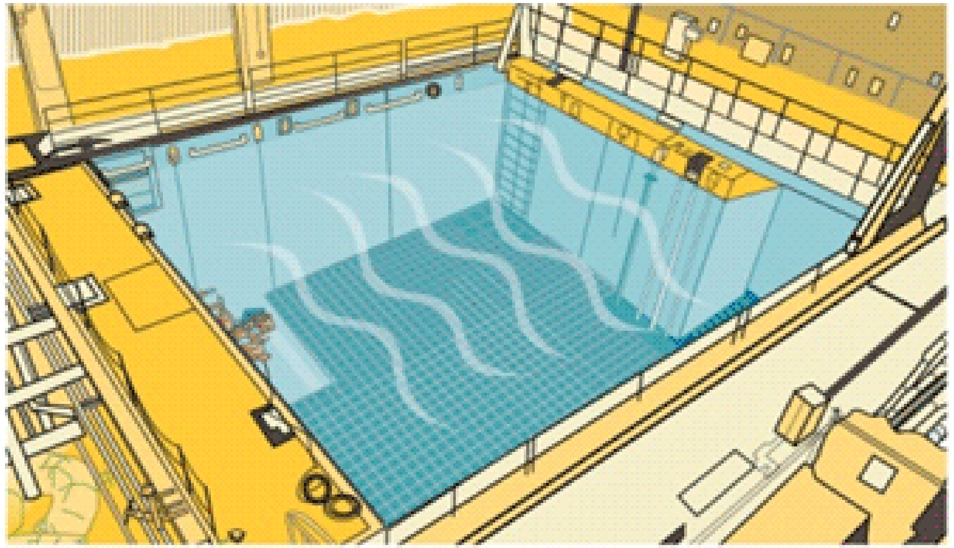
Lightbridge fuel

...and molten salt fuel and...?

Spent Nuclear Fuel Storage Overview

Initial Spent Nuclear Fuel Storage

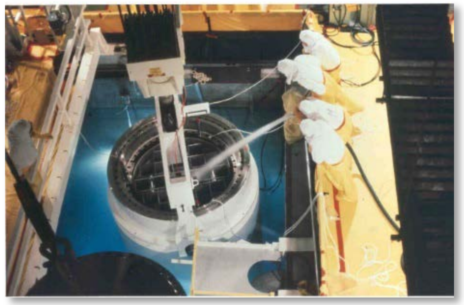
- **Pool Storage:** Every current reactor site has at least one pool into which spent nuclear fuel is placed for storage when it is removed from the reactor vessel
  - Located inside the plant's protected area
  - Robust, with very thick, steel-reinforced concrete walls and stainless-steel liners
  - Contains an enormous amount of water to cool the fuel and provide radiation shielding
  - Have no drains that would allow the water to drain out
  - Can be filled using a variety of water sources, if needed



Spent fuel is placed in pools for storage

NRC's Spent Nuclear Fuel Storage Responsibilities

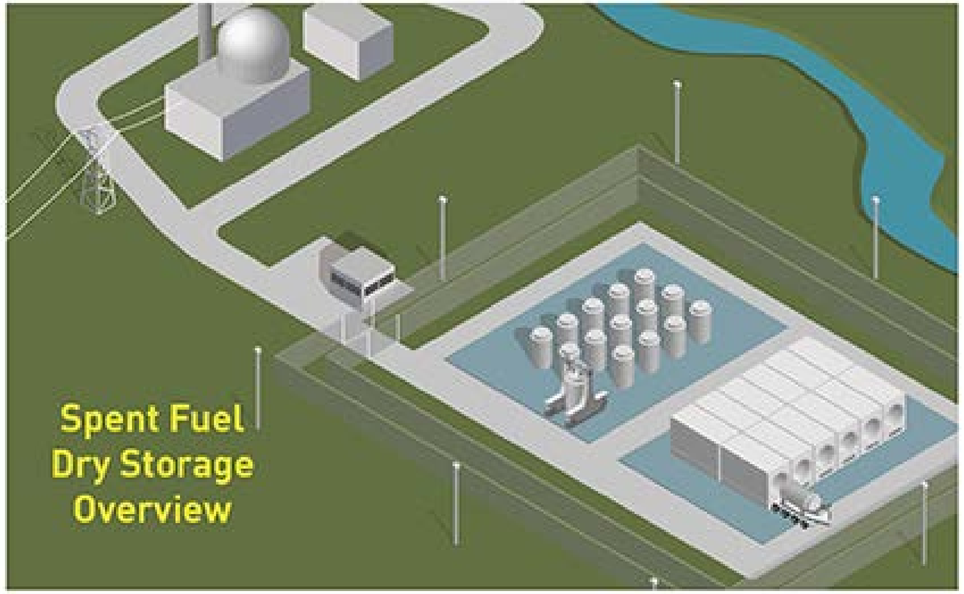
- NRC establishes safety, security, and environmental regulations for:
  - Licensing of independent spent fuel storage installations (ISFSIs)
  - Certification of cask designs for dry storage of SNF
- NRC currently licenses and oversees 82 ISFSIs in 36 States
- NRC has issued certificates of compliance (CoCs) for 15 different dry storage cask designs for use at reactor sites
- NRC inspects and oversees applicants and licensees during
  - Construction, operation, and decommissioning of interim storage facilities
  - Manufacturing of dry storage casks and systems



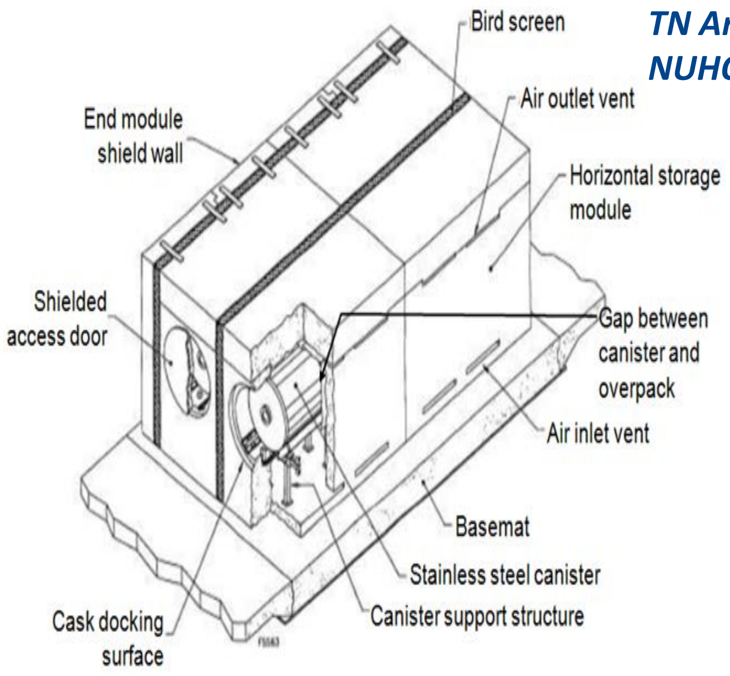
Locations of NRC-Licensed Independent Spent Fuel Storage Installations (ISFSI)

Regulations for ISFSI and CoC Licensing

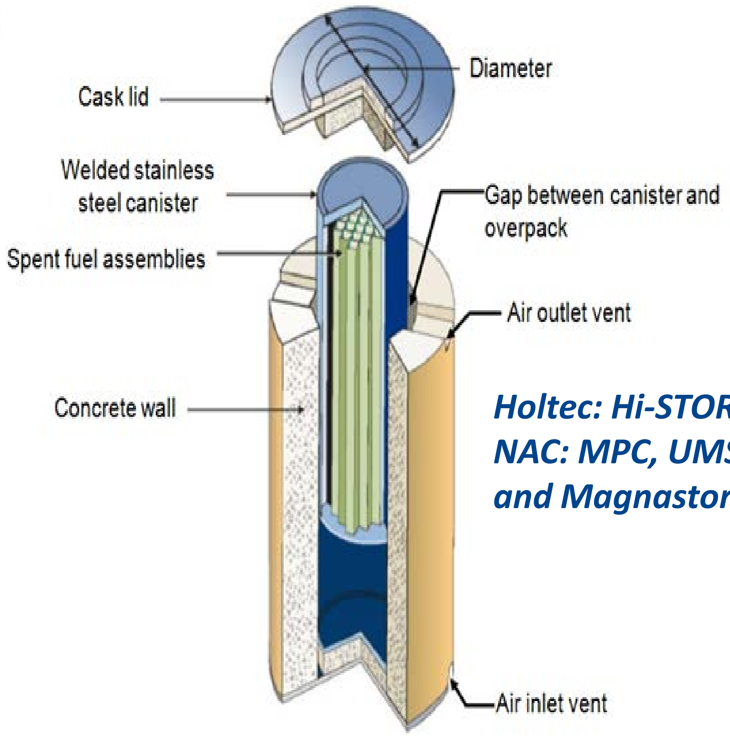
- Title 10, Part 72, of the Code of Federal Regulations, “Licensing Requirements for the Independent Storage of SNF, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste”
  - Subpart B: Site Specific Licensing
  - Subpart K: General Licenses
  - Subpart L: Approval of SNF Storage Casks (CoCs)



ISFSI Designs & NRC Licensing Reviews



TN Americas: NUHOMS



Holtec: Hi-STORM
NAC: MPC, UMS, and Magnastor

- Safety and Security Review includes:
  - Maintaining confinement of radioactive material,
  - Providing adequate radiation shielding for workers and the public,
  - Preventing nuclear criticality, and
  - Maintaining retrievability of SNF
- Environmental Review
  - Analyzes environmental impacts of the proposed action consistent with NEPA
- NRC Adjudicatory Hearings
  - Opportunity for the public to request an adjudicatory hearing before NRC's Atomic Safety and Licensing Board Panel (ASLBP)

SNF Storage Cask Manufacturers & Designs

- Currently 4 manufacturers with 15 different cask/storage system designs authorized for use under a General ISFSI License
  - Westinghouse
  - TN Americas
  - NAC International
  - Holtec

Disposal of Spent Nuclear Fuel and High-Level Waste

- The U.S. National Program is for disposal in a deep geological repository
- Specific roles for government agencies
  - DOE is the developer of the repository
  - NRC is the regulator (10 CFR Parts 60 and 63)
  - EPA sets health standards (40 CFR Parts 191 and 197)
- SNF continues to be safely stored and protected under NRC regulations and oversight in accordance with 10 CFR Parts 72 and 73.
- NRC's Yucca Mountain proceeding is currently suspended

Transportation of Radioactive Material, including Spent Nuclear Fuel

Radioactive Material Transport Safety & Security

- Over 3 million packages of RAM are shipped each year in the U.S. either by truck, rail, air, or water; mostly, truck

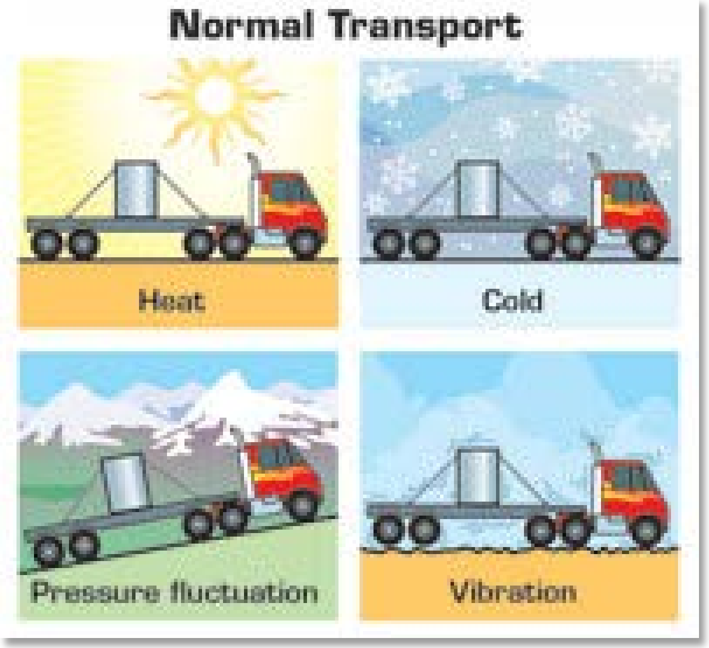
- WY, U.S. Nuclear Regulatory Commission (NRC) and U.S. Department of Transportation (DOT) are co-regulators

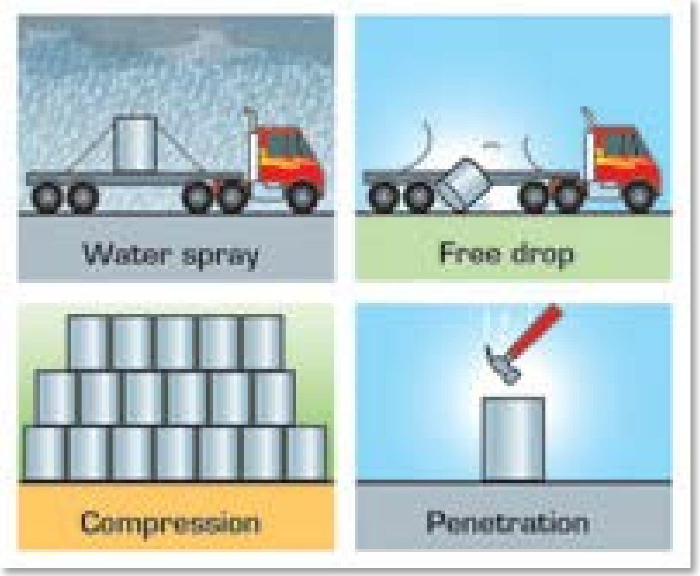
- DOT regulates the conveyances and All HAZMAT shipments, and sets minimum transportation security standards
  - Highway Route Control Quantity (HRCQ) – Class 7 radioactive shipments
  - NRC requires additional security under 10 CFR Part 37 for Category 1 and Category 2 RAM
  - NRC requires additional security for SNF shipments in 10 CFR 73.37.

Normal Conditions of Transport Tests for Type B Packages

Per 10 CFR 71.71:

1. Heat
2. Cold
3. Pressure changes
4. Vibration
5. Water spray
6. Free drop
7. Compression
8. Penetration

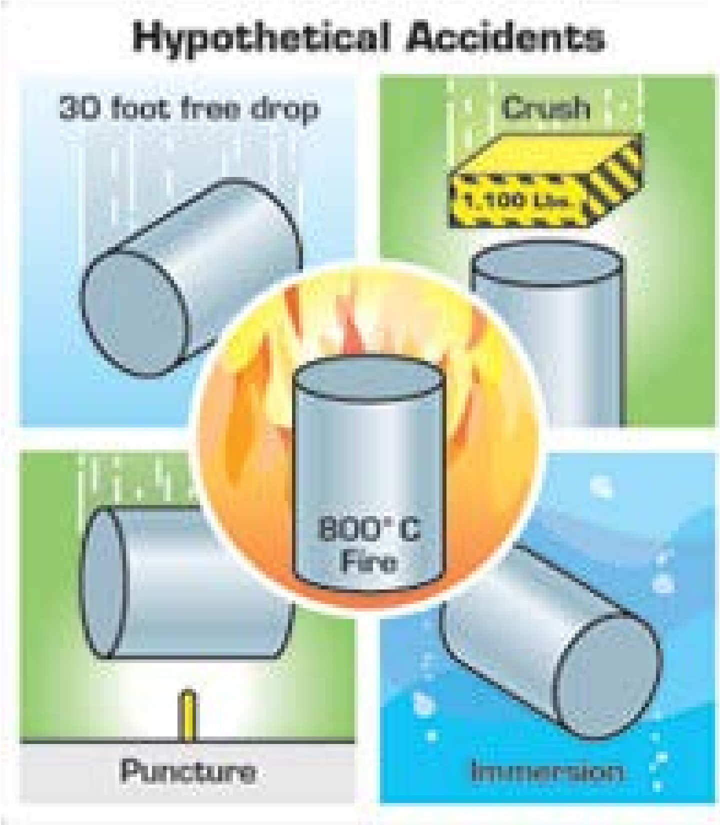




Hypothetical Accident Condition Tests for Type B Packages

Per 10 CFR 71.73:

1. Free Drop
2. Crush
3. Puncture
4. Thermal
5. Immersion - fissile package
6. Immersion - all packages



RAM Transport Security (cont'd)

- NRC security requirements for ***Category 2 RAM*** include:
  - Carrier: Have a tracking system to track package/require signature
  - Pre-planning/coordination between licensee and receiver
  - Maintain constant control/surveillance
- NRC security requirements for ***Category 1 RAM*** include:
  - Movement control center (MCC) receives location updates
  - Pre-planning/coordination between licensee, State & receiver
  - Law enforcement escort, as determined by each State
  - Identify safe havens
  - Redundant communications
  - Develop contingency procedures and communication protocols
  - Trustworthy/reliability determinations for access to RAM
  - Advance notices provided to State and NRC; NRC forwards notices to Federal partners for awareness

RAM Transport Security (cont'd)

- General NRC security requirements for ***SNF shipment:***
  - Pre-planning/coordination between licensee, State & receiver for SNF shipment, Law Enforcement contacts along the route and safe haven locations
  - Licensee obtains NRC approval for SNF routes: 5 yrs road, 7 yrs rail
  - Develop contingency procedures and communication protocols
  - Background investigation over the past 10 yrs including personal history, criminal history (FBI fingerprint check), verification of identity, employment history and/or education, credit history
  - Advance notices provided to State, Tribes and NRC (10 days in advance); NRC forwards notices to Federal partners for awareness
  - Shipments monitored 24/7 by MCC
  - Vehicle equipped w/NRC approved immobilization device
  - Includes Armed Escorts (may be Local Law Enforcement)
  - Redundant communications
  - Shipment details are Safeguards Information (AEA-designated security related info)

RAM Transport Security Training

- Tabletop Exercises (TTX) Sponsored by DOE/FBI:
  - TTX are conducted in major U.S. cities/territories where RAM passes through or are delivered
  - TTX are one day, no-fault exercise involving Local, State and Federal agencies
  - Scenario involving the theft/diversion of 10 CFR Part 37 Category 1 RAM during transit to an NRC licensee for use in a radiological dispersal device (RDD); to be detonated by a terrorist cell, at a soft target in a major city
- The purpose of the exercise is to improve radiological response understanding, promote joint situational awareness, team building, and problem resolution
- Remaining TTX for 2025:
  - Boston, MA (7/23/25) and Pittsburgh, PA (8/20/25)
- 2026 TTX (dates TBD):
  - Nashville, TN; Washington DC; EL Paso, TX; Las Vegas, NV; possibly Jackson, MS
- If interested in witnessing a TTX in person or to learn more, contact the NRC

Thank you for the opportunity…

- Opportunity to present before Wyoming Legislative Committee is consistent with NRC Values and Principles of Good Regulation, including
  - Openness
  - Clarity
  - Cooperation
- NRC will continue to engage with Wyoming
  - Kemmerer Power Station Construction Permit Application
  - Any future license applications for NRC-regulated activities in the state
  - With our Co-Regulating Partner (WY DEQ)

Contact & References

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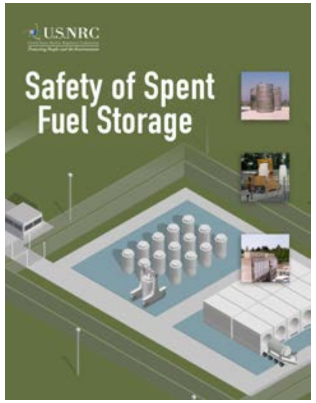
NUREG/BR-0528, "Safety of Spent Fuel Storage"

https://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0528/index.html



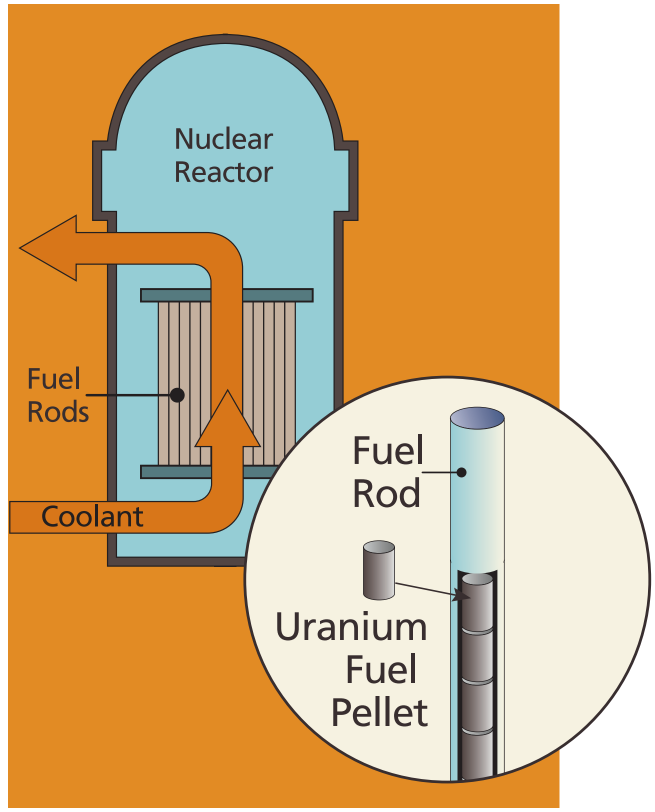
NUREG/BR-0292, "Safety of Spent Fuel Transportation"

https://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0292/index.html

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Safety of Spent Fuel Storage

What Is Spent Fuel?



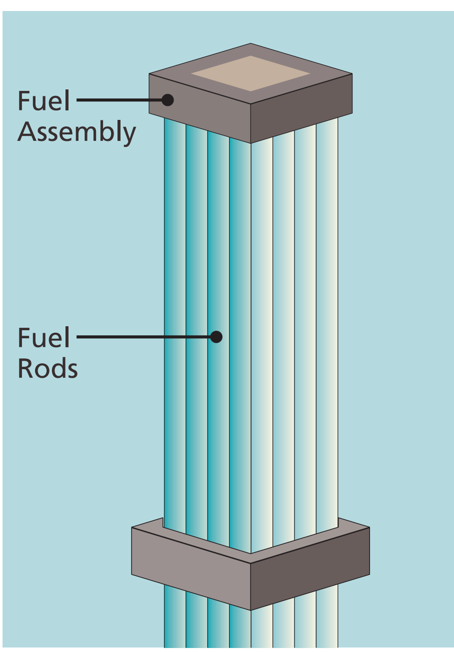
Nuclear reactors use uranium fuel rods bundled into fuel assemblies to generate the heat that turns generators. These generators produce electricity that powers people's homes.

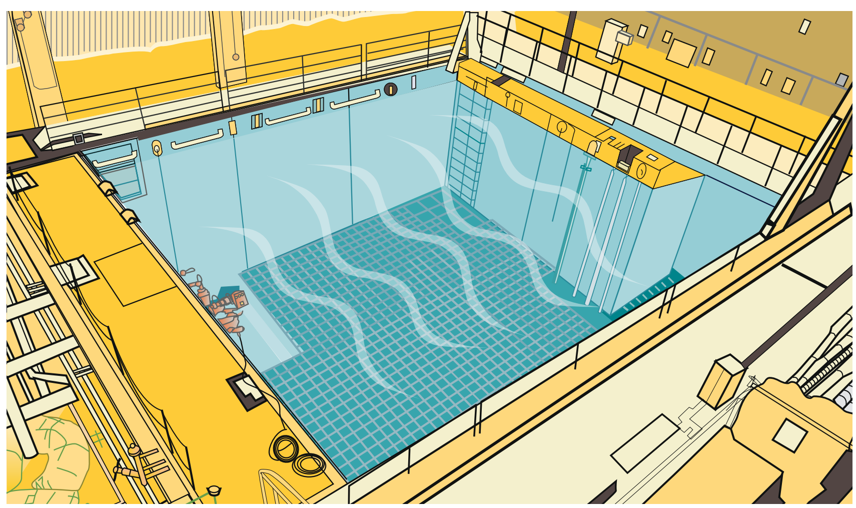
As it burns in the reactor, this fuel becomes very hot and very radioactive. After about 5 years, the fuel is no longer useful and is removed. Reactor operators have to manage the heat and radioactivity that remains in this spent fuel.

In the United States, every reactor site has at least one pool on site for spent fuel storage. Plant personnel move the spent fuel underwater from the reactor to the pool. Over time, spent fuel in the pool cools as the radioactivity decays away.

These pools were intended to provide temporary storage. The idea was that after a few years, the spent fuel would be shipped offsite to be reprocessed, or separated so usable portions could be recycled into new fuel. But reprocessing did not succeed in the United States, and the pools began to fill up.

In the early 1980s, reactor operators began to look for ways to increase the amount of spent fuel they could store onsite. They began to place fuel in dry casks that could be stored in specially built facilities on their sites. Most nuclear plants today use dry storage.





Spent fuel pool

Dry Cask Storage—The Basics

At least 23 feet of water covers the fuel assemblies in the spent fuel pool of Unit 2 at the Brunswick Nuclear Power Plant in Southport, NC.
(Courtesy: Matt Born/Wilmington Star-News)

A dry cask storage system is a cylinder that operators lower into the pool and fill with spent fuel. They raise the cylinder, drain, and dry it, before sealing and placing it outdoors on a concrete pad. There are many varieties of spent fuel storage casks. They all need to:

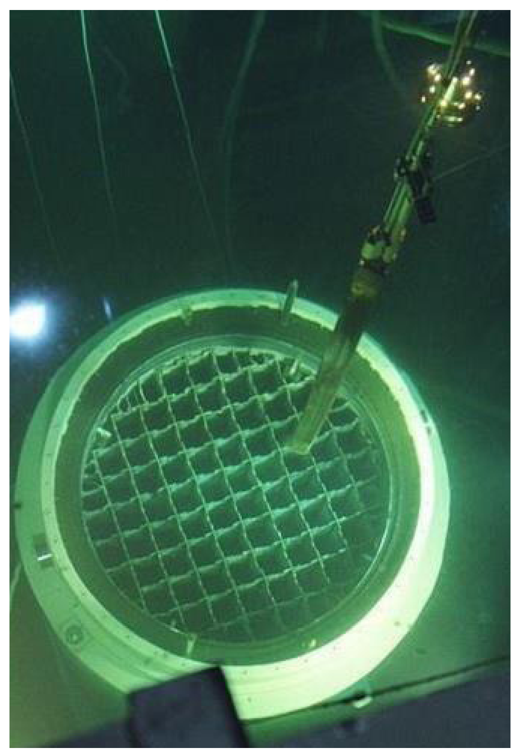
- Maintain confinement of the spent fuel
- Prevent nuclear fission (the chain reaction that allows a reactor to produce heat)
- Provide radiation shielding
- Maintain the ability to retrieve the spent fuel, if necessary
- Resist earthquakes, tornadoes, floods, temperature extremes, and other scenarios.

Casks come in different sizes. They are tall enough to hold spent fuel, which can be up to 14 feet long, and they can weigh up to 150 tons—as much as 50 midsize cars. Plants may need a special crane that can handle heavy loads to be able to lift a loaded cask full of water out of the pool for drying. After the casks are dried, robotic equipment is used to seal them closed to keep doses to workers as low as possible.

Two basic designs are in wide use today. Welded, canister-based systems feature an inner steel canister that contains the fuel surrounded by 3 feet or more of steel and concrete. The canisters may be oriented either vertically or horizontally. In bolted cask systems, there is no inner canister. Bolted casks have thick steel shells, sometimes with several inches of radiation shielding inside.

Plants use special transporters to move the loaded cask outdoors to where it will be stored. At that point, the radioactivity from the cask must be less than 25 millirem per year at the site boundary. That means the highest dose allowed to someone standing at the fence for a full year is about the dose someone would receive going around the world in an airplane. The actual dose at the site boundary is typically much lower.

Dry cask storage has proven to be a safe technology over the 30 years it has been used. Since the first casks were loaded in 1986, dry storage has released no radiation that affected the public or contaminated the environment. As of January 2017, more than 2,400 casks have been loaded and are safely storing 100,000 spent fuel assemblies. Tests on spent fuel and cask components after years in dry storage confirm that the systems continue to provide safe storage.



Loading spent fuel cask under water.
(Courtesy: Holtec International)

The U.S. Nuclear Regulatory Commission (NRC) analyzed the risks from loading and storing spent fuel in dry casks. Two separate studies found the potential health risks are very, very small. To ensure continued safe dry storage of spent fuel, the NRC is further studying how the fuel and storage systems perform over time. The NRC is also staying on top of related research planned by the Department of Energy and the nuclear industry.

Workers prepare to load an AREVA-TN NUHOMS canister into a concrete storage module at the Calvert Cliffs Nuclear Power Plant in Lusby, MD. (Courtesy: Exelon)

What We Regulate and Why

The NRC oversees the design, manufacturing, and use of dry casks. This oversight ensures licensees and designers are following safety and security requirements, meeting the terms of their licenses, and implementing quality assurance programs.

The NRC's regulations appear in Chapter 10 of the Code of Federal Regulations*, also known as 10 CFR.*

Cask designers must show that their systems meet the NRC's regulatory requirements. The NRC staff reviews cask applications in detail. The agency will only approve a system that meets NRC requirements and can perform safely. NRC inspectors visit cask designer offices, fabricators and spent fuel storage facilities to ensure they are meeting all our regulations. Cask design applications, the NRC's documentation of reviews, and NRC inspection reports are available to the public on the agency website at www.nrc.gov.

There are strict security requirements in place to protect the stored fuel. Security has multiple layers, including the ability to detect, assess, and respond to an intrusion. Our general security requirements for dry cask storage are in 10 CFR Part 73 (https://www.nrc.gov/reading-rm/doc-collections/cfr/part073/). The specific requirements in NRC orders and the licensee's security plans are not available to the public, as they could give an adversary the ability to defeat the security measures and compromise the safety systems. There have been no known or suspected attempts to sabotage cask storage facilities.

The NRC's requirements for dry cask storage can be found in 10 CFR Part 72 (https://www.nrc.gov/reading-rm/doc-collections/cfr/part072/), which requires all structures, systems, and components important to safety to meet quality standards for design, fabrication, and testing. Part 72 and related NRC guidance on casks and storage facilities also detail specific engineering requirements.

The NRC has dozens of experts in different scientific and engineering disciplines whose job is to review cask applications (which can be hundreds of pages long) and the detailed technical designs they contain. The agency will only approve a storage cask design if these experts are satisfied that all the specific safety requirements in each discipline have been met.

Cask transporter moves loaded spent fuel storage cask to storage pad.

The following sections discuss technical evaluations the NRC conducts during technical reviews of dry cask storage.

Materials

NUHOMS horizontal spent fuel storage system under construction at the Calvert Cliffs Nuclear Power Plant in Lusby, MD.

Materials—the stuff of which everything is made. In every case—the metal in a car door, the plastic used in airplane windows, or the steel used in elevator cables—the selection of appropriate materials is critical to safety.

Systems that transport and store spent nuclear fuel and other radioactive substances are made of a variety of materials. All of them are reviewed to confirm that those systems can protect the public and environment from the effects of radiation. The NRC does not dictate what materials are used. Rather, the NRC evaluates the choice of materials proposed by applicants. What makes a material "appropriate" to transport and store radioactive substances depends on a number of factors.

First, materials must be adequate for the job. In other words, the mechanical and physical properties of the materials have to meet certain requirements. For example, the steel chosen for a storage cask has to withstand possible impacts such as from tornadoes or earthquakes.

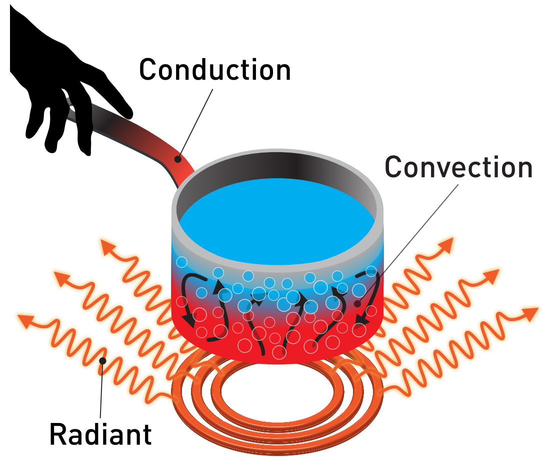
Next, when making a complex metal system, parts often are welded together—that is, partially melted—in a way that ensures that the joints themselves are adequate. The welder actually creates a new material at the joint with its own unique properties. That is why the NRC looks at how this is done, including the selection of weld filler metals, how heat is controlled to ensure good welds, and the use of examinations and testing to verify that no defects are present.

Finally, the NRC considers how materials degrade over time. Reviewers must take into account a material's chemical properties, how it was manufactured, and how it reacts with its environment. Just as iron rusts and elastic materials become brittle over time, all materials can degrade. This degradation and its impact must be well understood. Materials must be selected based on their present condition and their projected condition throughout their lifetimes.

Loaded vertical HI-STORM 100 casks are storing spent fuel at the Diablo Canyon Power Plant in Avila Beach, CA.

Best practices for appropriately selecting materials and the processes used to join them often can be found in consensus codes and standards. These guidelines are typically developed over many years of operational experience, and through industrywide and government technical discussions and agreement. The NRC also relies on both historical operating experience and the latest materials performance and testing data.

Managing Heat



Three different methods transfer heat.

Keeping the spent fuel from getting too hot is one way to ensure casks will be safe. The NRC requires the cask and fuel to remain within a certain temperature range. These requirements protect the cladding (the metal tube that holds the fuel pellets). As the fuel cools, heat is transferred from inside the cask to the outside. NRC experts examine how that heat will move through the cask and into the environment.

The method used to remove heat has to be reliable and provable. It must also be passive—that is, without the need for electrical power or mechanical device. Casks use conduction, convection, and radiation to transfer the heat to the outside.

Conduction transfers heat from a burner through a pot to the handle. The process of heat rising (and cold falling) is known as convection. The heat coming from a hot stove is known as radiant heat.

These methods work the same way in a storage cask. Where the structure containing the fuel touches the fuel assemblies, it conducts heat toward the outside of the cask. Most casks have vents that allow outside air to flow naturally into the cask and around the canister to cool it (convection). And most casks would feel warm to the touch from radiant heat, much like a home radiator.

The NRC also confirms that the pressure inside a cask is below the design limit so it will not impact the structure or operations. Technical experts review applications for cask designs carefully to verify that the fuel cladding and cask component temperatures and the internal pressure will remain below specified limits.

Each storage cask is designed to withstand the effects from a certain amount of heat. This amount is called the heat load. The NRC reviews whether the designer correctly considered how the heat load will affect cask component and fuel temperatures, and how this heat load was calculated. Cask designs must show that heat from spent fuel can be effectively transferred to the outside of the cask.

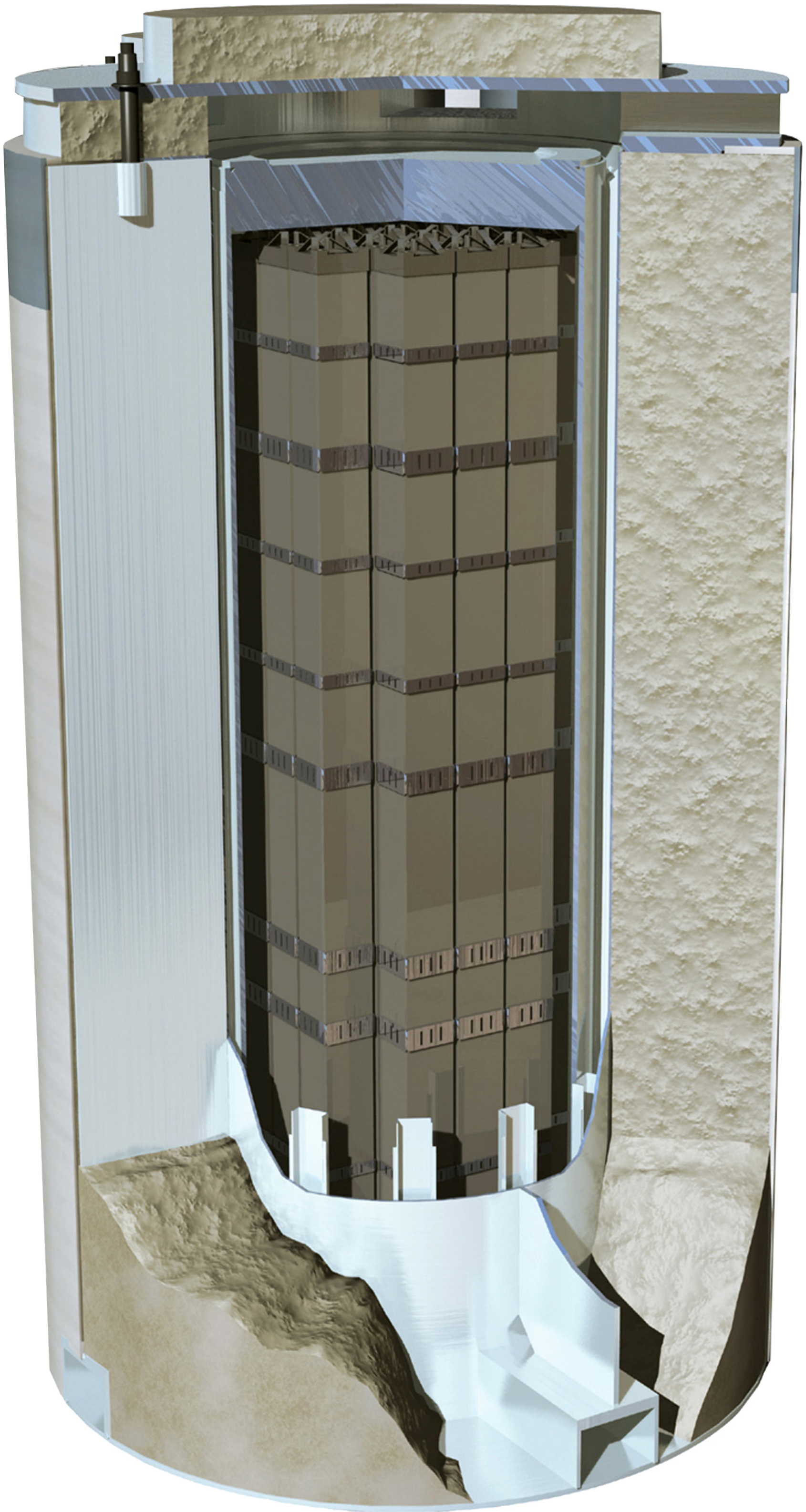
The NRC's review also verifies that the cask designer looked at all the environmental conditions that can be expected to affect cask components and fuel temperatures. These conditions may include windspeed and direction, temperature extremes, and a site's elevation. To make sure the right values are considered, the NRC verifies that they match the historical records for a site or region.

NRC reviewers consider all of the methods used to prove that the storage system can handle the specified heat loads. They verify computer codes, making sure they are the latest versions and have been endorsed by experts. They look at the values used in the codes, such as for material properties, and confirm calculations for temperature and pressure. The NRC might run its own analysis using a different computer code to see if those results match the application.

Making Sure Casks Will Hold Up

In its application, the cask designer must provide an evaluation that shows the system will be strong and stable enough to perform its safety functions even after experiencing a load, such as if the cask were dropped. NRC reviewers examine the structural design and analysis of the system under all credible loads for normal conditions—that is, planned operations and environmental conditions that can be expected to occur often during storage. They also look at accidents, natural events, and conditions that can be expected to occur from time to time, but not regularly.

The NRC review looks at whether the cask designer evaluated the proper loading conditions. It will also ensure the designer evaluated the system's response to those loads accurately and completely. Reviewers must verify whether the resulting stresses in the material meet the acceptance criteria in the appropriate code. The NRC's review also looks at several different realistic combinations of loads. These cases are analyzed to determine the stresses placed on the material used to construct the cask system. To be conservative, the NRC and the designers overestimate loads and underestimate material strength. Doing this enhances the NRC's assurance that the design is adequate.



Cutaway of spent fuel storage cask shows spent fuel assemblies surrounded by steel and thick concrete shielding.

Confinement

Loaded spent fuel storage casks are in place on storage pad at the Haddam Neck Plant in Meriden, CT. (Courtesy: Connecticut Yankee)

The cask design must prevent the release of radioactive material. This role is performed by the confinement boundary, which usually includes a metal canister with a lid that has at least two closures. Some casks have two separate lids that are each welded closed. Others are bolted and have two separate seals. Having both closures provides an extra layer of protection to ensure the radioactive materials remain confined.

The design must also keep the fuel assemblies in a protected, or "inert," environment. This is important to keep the fuel cladding from degrading. Once the water is removed from inside the cask, it is filled with a gas such as helium that will not react with fuel cladding.

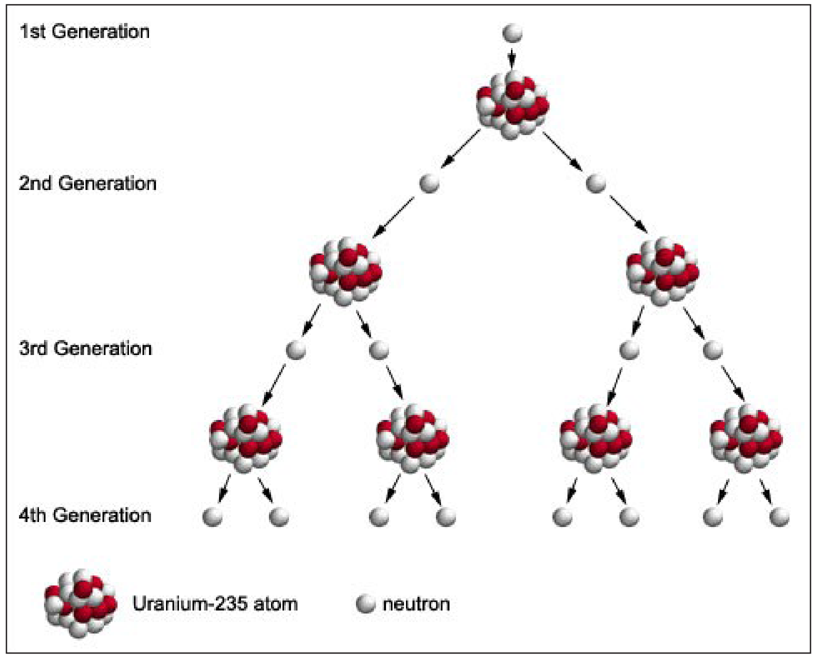
Cask users must monitor the confinement boundary. The monitoring requirements depend on whether a cask is bolted or welded. Bolted confinement boundaries with O-ring seals need to have alarms to alert the user if a seal starts to leak. In that case, the seal would need to be repaired or replaced to ensure the cask continues to have redundant confinement. Our experts review the proposed monitoring programs to make sure they are adequate. Welded closures do not need to be monitored in the same way. This is because the welds are examined closely after they are made to ensure they do not leak.

The NRC's review of a cask's confinement boundary looks at the "source term." This is the inventory of radioactive material inside the cask. While the redundant closures and other requirements ensure the material will remain safely confined, the NRC requires cask designers to look at the dose rates in case some material were to come out. They also need to analyze how those dose rates compare to the NRC's regulatory limits.

Loaded spent fuel storage cask on transporter is moved from the fuel handling building at the Surry Power Station in Surry, VA.

Finally, cask designers must provide an analysis of how the confinement boundary works. Casks must be designed and tested to meet criteria approved by the American National Standards Institute, or ANSI. The ANSI standard for leak tests on radioactive materials packages was put together by a committee of experts and went through a lengthy review and approval process before it was adopted.

Criticality Safety



Neutrons cause uranium-235 atoms to split in a nuclear chain reaction.

The nuclear chain reaction used to create heat in a reactor is known as fission. In this process, uranium atoms in the fuel break apart, or disintegrate, into smaller atoms. These atoms cause other atoms to split, and so on. Another word for this process is criticality.

The potential for criticality is an important thing to consider about reactor fuel throughout its life. Fuel is most likely to go critical when it is fresh. The longer the fuel is in the reactor, the less likely it is to go critical. This is why it is removed from the reactor after several years—it loses energy and will no longer easily support a self-sustaining chain reaction. Once fuel is removed from the reactor, the NRC requires licensees to ensure it will never again be critical. This state is referred to as "subcriticality."

Subcriticality is required whether the fuel is stored in a pool or a dry cask. It is required for both normal operating conditions and any accident that could occur at any time.

Many methods help to control criticality. The way spent fuel assemblies are positioned is an important one. How close they are to each other and the burnup of (or amount of energy extracted from) nearby assemblies all have an impact. This method of control is referred to as fuel geometry.

Certain chemicals, such as boron, can also slow down a chain reaction by absorbing neutrons released during fission, and keeping them from striking other uranium atoms.

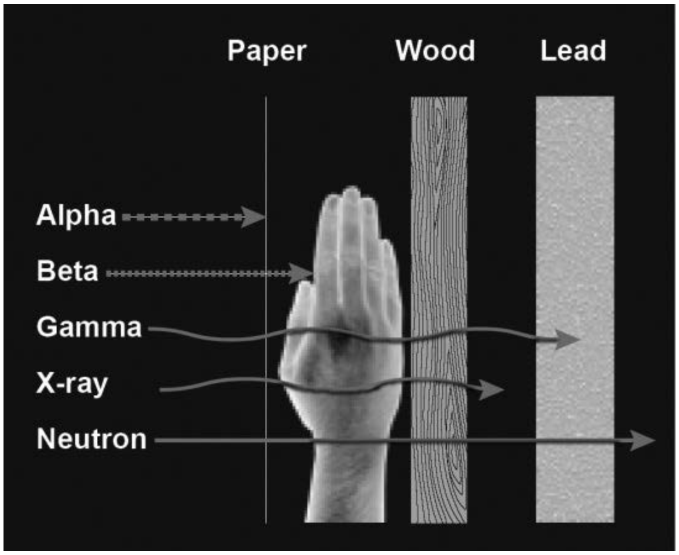
Casks have strong baskets to maintain fuel geometry. They also have solid neutron absorbers, typically made of aluminum and boron, between fuel assemblies. A cask application must include an analysis of all the elements that contribute to criticality safety during both normal and accident conditions.

NRC technical experts review this analysis to verify several things:

- The factors that could affect criticality have been identified.
- The models address each of these factors in a realistic way.
- Any assumptions used in the models are conservative—they result in more challenging conditions than would actually be expected.

Radiation Shielding

The fission process turns uranium into a number of other elements, many of which are radioactive. These elements continue to produce large amounts of radiation even when the fuel is no longer supporting a chain reaction. Shielding is necessary to block this radiation and protect workers and the public.



Different types of radiation have different properties.

The four major types of radiation differ in mass, energy, and how deeply they penetrate people and objects. Alpha radiation—particles consisting of two protons and two neutrons—are the heaviest type. Beta particles—free electrons—have a small mass and a negative charge. Neither alpha nor beta particles will move outside the fuel itself.

But spent fuel also emits neutron radiation (particles from the nucleus that have no charge) and gamma radiation (a type of electromagnetic ray that carries a lot of energy). Both neutron and gamma radiation are highly penetrating and require shielding.

Shielding for the two main types of dry storage casks is configured in slightly different ways. For welded, canister-based systems, the thick steel-reinforced concrete vault that surrounds an inner canister provides shielding for both neutron and gamma radiation. Shielding in bolted cask systems comes from their thick steel shells that may have several inches of lead gamma shielding inside. These systems have a neutron shield on the outside consisting of low-density plastic material, typically mixed with boron to absorb neutrons.

The NRC's reviews ensure that dry cask designs meet regulatory limits on radiation doses at the site boundary, under both normal and accident conditions, and that dose rates in general are kept as low as possible. Every applicant must provide a radiation shielding analysis. This analysis uses a computer model to simulate how radiation penetrates through the fuel and into thick shielding materials under normal operating and accident conditions. Reviewers ensure the analysis has identified all the important radiation-shielding parameters and models them conservatively, in a way that maximizes radiation sources and external dose rates.

At right, a dry storage cask recently loaded with spent fuel is lifted from a horizontal transporter to be placed on a specially designed storage pad. (Courtesy: Sandia National Laboratories)

Inspections

Inspectors examine dry storage casks containing spent nuclear fuel.

As part of its oversight function, the NRC inspects the companies that design and fabricate dry storage casks and the facilities that use them. Inspectors from NRC headquarters and the four regional offices conduct these inspections and issue their findings in publicly available reports.

Cask designers are responsible for ensuring that the fabricated cask components comply with the design as approved by the NRC. To do this, they are required to have a quality assurance program that meets the 18 criteria described in NRC dry storage regulations. The NRC reviews and approves these programs.

The designers must make sure their quality assurance programs are properly implemented during both design and fabrication. The NRC conducts periodic safety inspections to independently assess and verify that the designers are doing so. Some inspections look at design activities carried out at corporate offices. At fabrication facilities, both in the United States and overseas, NRC inspectors look at controls for fabrication, the process for verifying that the fabricated components comply with the approved design, and how the designer ensures that the fabricator meets its quality assurance program.

Each licensee is responsible for ensuring that its storage facility meets NRC regulations during construction and operation. NRC inspectors verify that the licensees are properly implementing the regulations. These inspections cover the design and construction of the concrete pad or modules that support the storage casks, preoperational testing (also referred to as dry runs), cask loading, and routine monitoring of operating dry storage facilities.

Transportable spent fuel storage casks sit on a storage pad.
(Courtesy: Holtec International)

Managing Aging

Cutting-edge robotic technology is making it easier to inspect inside spent fuel dry cask storage systems. As these casks remain in use for longer time frames, the ability to inspect canister surfaces and welds will become an important aspect of the NRC's confidence in their safety.

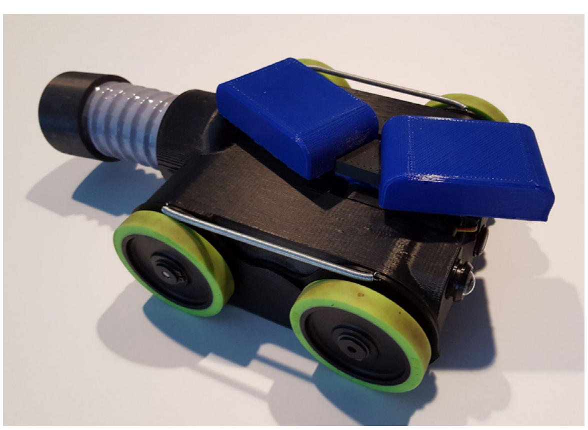
The techniques for inspecting canister surfaces and welds have been used for decades. These techniques are collectively known as nondestructive examination (NDE) and include a variety of methods, such as visual, ultrasonic, eddy current, and guided wave examinations.

Cutaway mockup of NAC International MAGNASTOR cask system at Palo Verde Nuclear Generating Station in Wintersburg, AZ. (Courtesy: EPRI/APS)

Robots are being developed to apply these NDE techniques inside casks. These robots need to fit into small spaces and withstand the heat and radiation inside the cask. The state-of-the-art robot technology is evolving quickly.

The Electric Power Research Institute and cask manufacturers have successfully demonstrated robotic inspection techniques to NRC staff several times at different reactor sites. These demonstrations are helping to refine the robots' designs.

In one demonstration, a robot inside a spent fuel storage cask maneuvered a camera with a fiber optic probe, which meets the industry code for visual examinations. The robot was able to access the entire height of the canister, allowing the camera to capture images of the fabrication and closure welds. The welds showed no signs of degradation. The canister was intact and in good condition.



Prototype robotic delivery system. (Courtesy: EPRI/RTT)

The robot was also able to obtain samples from surfaces of the cask and canister. These samples were analyzed for atmospheric deposits that could cause corrosion.

If degradation is identified, cask users would select their preferred mitigation and repair option. They would have to meet the NRC's safety requirements before implementing it.

Cask inspections are important to ensure continued safe storage of spent nuclear fuel, and robots will continue to be a helpful tool in this important activity.

For more information on spent fuel and dry cask storage, visit the NRC's website:

https://www.nrc.gov/waste/spent-fuel-storage.html

Cover Photos:

Top: Massive storage casks loaded with spent nuclear fuel sit on a concrete pad inside a secure storage facility.

Middle: A transportable spent fuel storage system is moved to a storage pad at the Peach Bottom Atomic Power Station in Delta, PA. (Courtesy: AREVA)

Bottom: A horizontal spent fuel storage system sits behind a secure fence at the Calvert Cliffs Nuclear Power Plant in Lusby, MD.

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U.S. Nuclear Regulatory Commission
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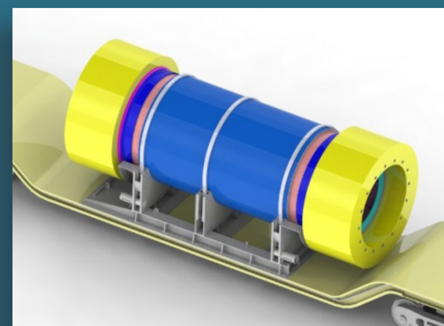
U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Safety of Spent Fuel Transportation




The Agencies: Who Does What?

The U.S. Nuclear Regulatory Commission (NRC) is an independent agency created by Congress. Its mission is to regulate the nation's civilian use of radioactive materials in a way that protects public health and safety and the environment. The NRC regulates commercial nuclear power reactors; research, test, and training reactors; nuclear fuel cycle facilities; and medical, academic, and industrial uses of nuclear materials. The NRC also regulates packaging for the transport, storage, and disposal of nuclear materials and waste, and licenses the export and import of radioactive materials.

The U.S. Department of Transportation (DOT) coordinates with the NRC to set rules for the packaging of nuclear materials. DOT also works with the NRC and affected States to regulate their transport. DOT regulates carriers, sets standards for routes, and is responsible for international agreements on the transport of all hazardous materials.

The U.S. Department of Energy (DOE) is responsible by law for disposal of spent fuel from the nation's nuclear power reactors.

The International Atomic Energy Agency (IAEA) is a forum for scientific and technical cooperation in the nuclear field. Part of the United Nations, the IAEA sets global regulations in many areas of the nuclear industry. IAEA's regulations for materials packaging and transport serve as a model for the United States and other nations.

Cover Photos:

(Left) Transportable spent fuel storage casks sit on a storage pad. (Courtesy: Holtec International)

(Middle) Spent fuel transport cask arrives at Rancho Seco. (Courtesy: Areva)

(Right) Schematic of spent fuel transport cask. (Courtesy: Holtec International)

(Bottom) Spent fuel transport cask arrives on site.

Page 1 Photos:

(Left) Empty transportable spent fuel storage system arrives at Prairie Island. (Courtesy: Areva)

(Right) Transportable spent fuel storage system is readied for storage. (Courtesy: Areva)

(Bottom) Transport package is placed inside conveyance vehicle. (Courtesy: NAC International)

The Nuclear Regulatory Commission

The NRC regulates the nuclear fuel cycle from beginning to end. Starting when the uranium is taken from the ground, the NRC oversees its processing and manufacture into fuel to be used in reactors. The NRC also plays a role in ensuring the safe transportation, storage, and permanent geologic disposal of used fuel.

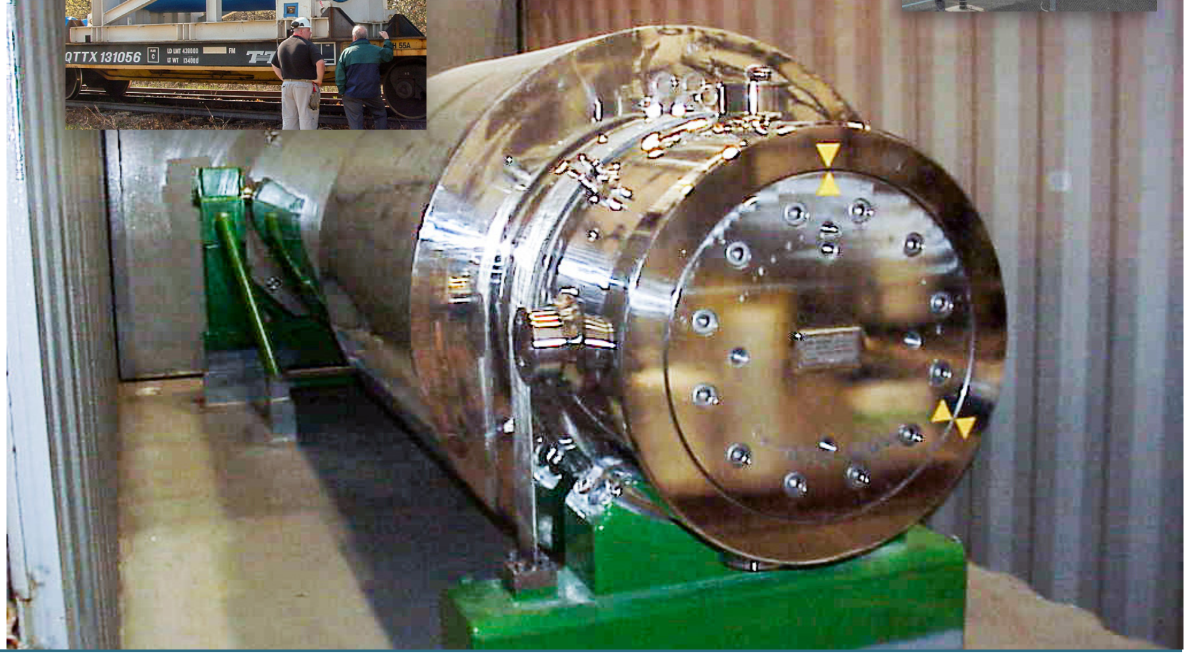
The NRC works to protect public health and safety, the environment, and our national security. To keep the public's confidence, the NRC aims to do its work openly and to be effective, efficient, and realistic.

Proper handling of nuclear materials helps to protect the safety of the public and plant workers. To achieve this aim, the NRC works with the DOT and DOE in the United States, and with the IAEA internationally. Together, these agencies help make sure nuclear materials are packaged and transported safely around the world.

This publication explains the NRC's role in the safe packaging and transport of spent nuclear fuel from commercial nuclear power plants. The NRC oversees the design, manufacture, use, and maintenance of containers for these radioactive shipments. However, the NRC does not control the timing or destination of spent fuel shipments.

The NRC has three main functions:

1. *To set standards and develop regulations*
2. *To issue licenses for nuclear facilities and nuclear materials users*
3. *To inspect facilities to ensure that NRC regulations are being met*



What is Spent Fuel?

Radiation

About half of the public's average annual radiation exposure comes from natural sources. These sources include radon, the human body, outer space, rocks, and soil. This natural radiation is called background and can vary greatly from place to place. Nearly all of the rest of an average person's exposure comes from medical sources, such as x-rays and diagnostic tests that are used in health care. Radiation that can be traced to radioactive materials transport makes up a tiny fraction of an average person's overall exposure. Such low levels of exposure are very unlikely to have any biological effect, but if they did they would be too small to be detectable. The human body responds to radiation in the same way whether it comes from natural or manmade sources.

Nuclear reactors make electricity and, as a waste product, spent fuel. Uranium fuel can power a reactor for a number of years until it needs to be replaced. The used fuel is then known as spent fuel. It must be stored safely until it can be shipped offsite.

The Nuclear Waste Policy Act sets a policy for safe, permanent disposal of spent fuel and other high-level radioactive wastes. Congress in 1987 selected Yucca Mountain in Nevada as the site to be studied for a repository deep underground. DOE applied to the NRC in 2008 for a permit to construct the repository there. But DOE withdrew its application in 2010. The NRC's role is to assess whether the facility would meet NRC regulatory requirements. Other policy considerations are up to DOE and Congress.

All nuclear power reactors move their spent fuel first into pools for storage on site. As the amount of spent fuel in the pool increases, many reactors are also using dry casks for storage. The NRC reviews and approves the designs for these systems.

The NRC would also review any proposal for central interim storage of spent fuel. Eventually, spent fuel will need to be transported to a central storage or disposal facility from sites around the country. These shipments would likely be made by rail or on public highways.

Because spent fuel is highly radioactive, people may wonder:

- **How does the NRC protect the public from radiation during transport?**
- **What is the likelihood one of these shipments will be involved in an accident?**
- **How well can the shipping containers withstand an accident and prevent the release of nuclear materials?**

The NRC addresses these and other questions as a part of its ongoing efforts to ensure safe transport. As new technology and real-world information become available, the NRC evaluates that information against its regulations. It is important to know that spent fuel has been shipped safely within the United States and abroad for more than 40 years.

The Key to Ensuring Safety: the Spent Fuel Shipping Container

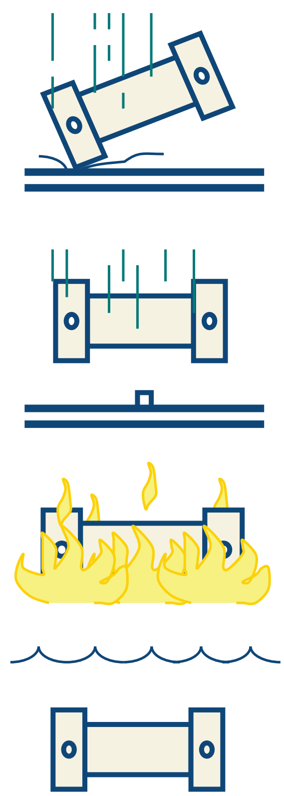
Spent fuel is highly radioactive and must be shielded and contained to be transported safely. Safe shipment requires a large, robust spent fuel container called a cask.

The NRC regulates the design and construction of these casks to ensure the public is protected. Containers used to move spent fuel by rail or highway are designed to withstand severe accidents. In the U.S. and internationally, these designs must pass a series of tests that mimic accident forces. The NRC reviews spent fuel containers very carefully to ensure they meet the design standards and test conditions in the regulations.

These containers must be able to survive four tests involving impact, puncture, fire, and submersion in water. During and after the tests, the casks must contain the nuclear material, limit radiation doses to acceptable levels, and prevent a nuclear chain reaction.

To protect workers and the public, a cask has walls of steel and shielding materials 5 to 15 inches thick and a massive lid. Truck containers weigh about 25 tons when loaded with one to two tons of spent fuel. Rail containers can weigh as much as 150 tons and can carry up to 20 tons of spent fuel. The ends of these transportation containers are encased in structures called impact limiters. In an accident, these impact limiters would crush and absorb the impact forces, protecting the package and its contents.

Spent fuel containers are tightly sealed and provide heavy shielding to protect anyone who might be near the cask during transport.



The NRC requires spent fuel shipping casks to survive four tests in sequence:

1. free-drop impact,

2. puncture impact,

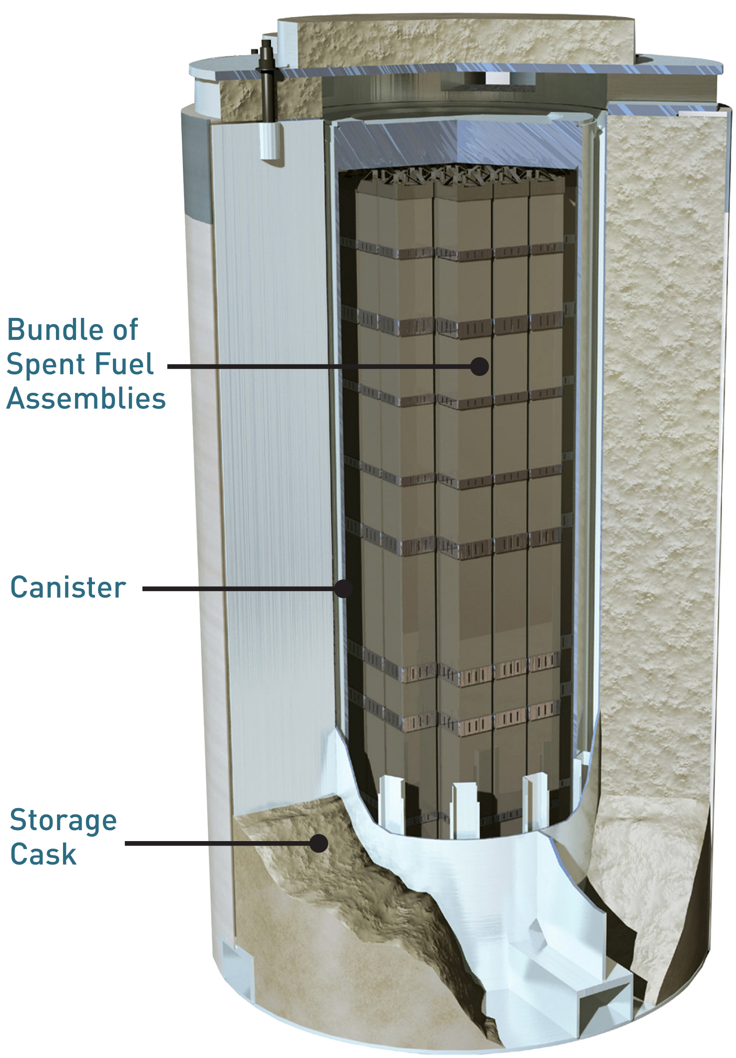
3. fire, and

4. water immersion.

Truck carries NAC LWT transport package.

Cask designers may use several techniques to demonstrate their containers are safe. They can use computer analyses, comparisons with other designs, component testing, physical testing of a scale model, or a combination of these techniques. Most often, they combine analyses and physical testing. They meet with technical review staff from the NRC, explain their design, and provide supporting documents in an application. The NRC evaluates each design, examines the information in depth, and performs its own calculations when needed. NRC reviewers are experts in different areas of science and engineering. They include structural and materials engineers and safety specialists with advanced degrees and many years of experience.

Once the NRC is satisfied that a design meets the requirements, it issues a certificate of compliance. This certificate describes the approved design (including what materials must be used), the authorized contents, and the dimensions of the container. Then the containers can be manufactured and used. Manufacturers and shippers have programs in place to ensure the containers meet design specifications throughout fabrication and transportation. These programs are known as quality assurance. To ensure the casks meet the certificates, NRC staff inspects both the manufacturer and the facilities that will use them.



But just having a certificate does not mean a cask can be used. Both NRC and DOT regulations also require a number of safety determinations before each spent fuel shipment. These include checks for leaks and tests to ensure radiation levels are within safe limits. These actions are designed to ensure that all aspects of every spent fuel shipment meet all the safety standards.

A Brief History of Spent Fuel Shipments and Studies

More than 1,300 spent fuel shipments have been completed safely in the United States over the past 35 years. Four were involved in accidents, but none resulted in a release of radioactive material or a fatality due to radiation exposure.

This experience confirms that the safety system is sound. But will this hold true when shipments increase to move spent fuel to a future repository or a storage facility?

The NRC looks at the risks associated with spent fuel transport in a methodical and scientific way. Several NRC-sponsored studies over the years have focused on the risk related to spent fuel transport on highways and railroads. The results provide additional confidence in the current regulations to assure the safety of spent fuel transport.

NAC LWT spent fuel transport package is moved by crane. (Courtesy: NAC International)

In a 1977 study[1], the NRC found the risk from transporting spent fuel to be low. The study gave the NRC confidence that existing regulations are adequate to protect the public.

In separate studies in 1987[2] and 2000[3], the NRC looked more closely at how shipping containers would perform in accidents. Each study used more advanced research methods than in the earlier studies. Both of these studies found the risk posed by spent fuel shipments would be even smaller than estimated in 1977. That finding holds true even if the number of spent fuel shipments were to increase greatly.

The latest risk study, published in January 2014, modeled the radiation doses people might receive from spent fuel shipments. This study again confirmed that NRC regulations for spent fuel transport ensure safety of the public and the environment.

The 2014 study[4] looked at how three NRC-certified packages would behave during both normal shipments and transportation accidents. The study modeled a variety of transport routes using population data from the U.S. Census Bureau. It used statistics from actual highway and rail accidents and state-of-the-art computer models. The study considered doses from normal shipments to people living along transportation routes. It also looked at doses to occupants of vehicles sharing the route, vehicle crews and other workers, and anyone present at a stop.

1. http://pbadupws.nrc.gov/docs/ML1219/ML12192A283.pdf
2. http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr4829/
3. http://pbadupws.nrc.gov/docs/ML0036/ML003698324.pdf
4. http://pbadupws.nrc.gov/docs/ML1403/ML14031A323.pdf

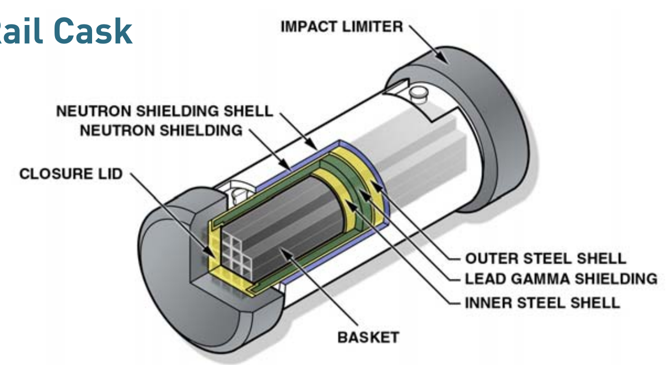
Transportable spent fuel storage cask moves to storage pad.
(Courtesy: Holtec International)

The risk assessment found:

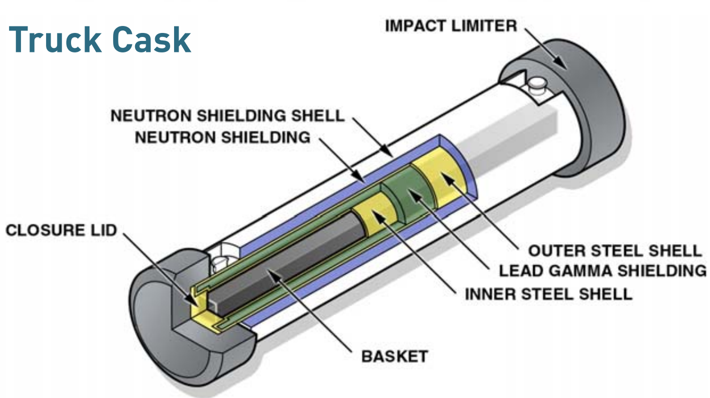
- **Doses from routine transport would be less than 1/1000 the amount of radiation people receive from background sources each year.**
- **There is less than a 1 in 1 billion chance that radioactive material would be released in an accident.**
- **If an accident did release radioactive material, the dose to the most affected individual would not cause immediate harm.**

In addition to these risk studies, the NRC has looked closely at real-world transportation accidents involving fires. The NRC did a series of case studies on the most severe accidents to see how well an NRC-certified spent fuel package would perform. These studies show the current regulations protect the public even in the most severe fires. The case studies include the Howard Street tunnel chemical fire that burned for five days in Baltimore in 2001; the 1982 Caldecott tunnel fire and the 2007 MacArthur Maze fire, both sparked by gasoline tankers outside Oakland, CA.; and a 2007 brush fire in the New Hall Pass tunnel outside Los Angeles.

Rail Cask



Truck Cask



Spent fuel containers are specially designed to protect the public by withstanding accident conditions without releasing their radioactive contents.

Additional NRC studies identified the conditions in an accident that could produce a fire severe enough to engulf a spent fuel transport package.

On the basis of these studies, plus operational experience and its own reviews, the NRC believes spent fuel can continue to be shipped safely. The evidence shows this will be true even if hundreds of shipments are made each year. The NRC is continuing to track spent fuel shipping, including more analyses and testing of spent fuel casks, to ensure that the risks remain low.

Understanding the Risks

Risk is generally understood to be the chance of injury, damage or some kind of loss. The spent fuel shipment record in the United States has been outstanding to date. Many more shipments have been successfully completed internationally under the same basic safety standards.

While shipping spent fuel does involve risk, NRC studies show this risk is low. As a part of its safety effort, the NRC aims to manage the hazards to minimize the risk. To evaluate the risks, the NRC asks the following three questions and then converts the answers into numbers:

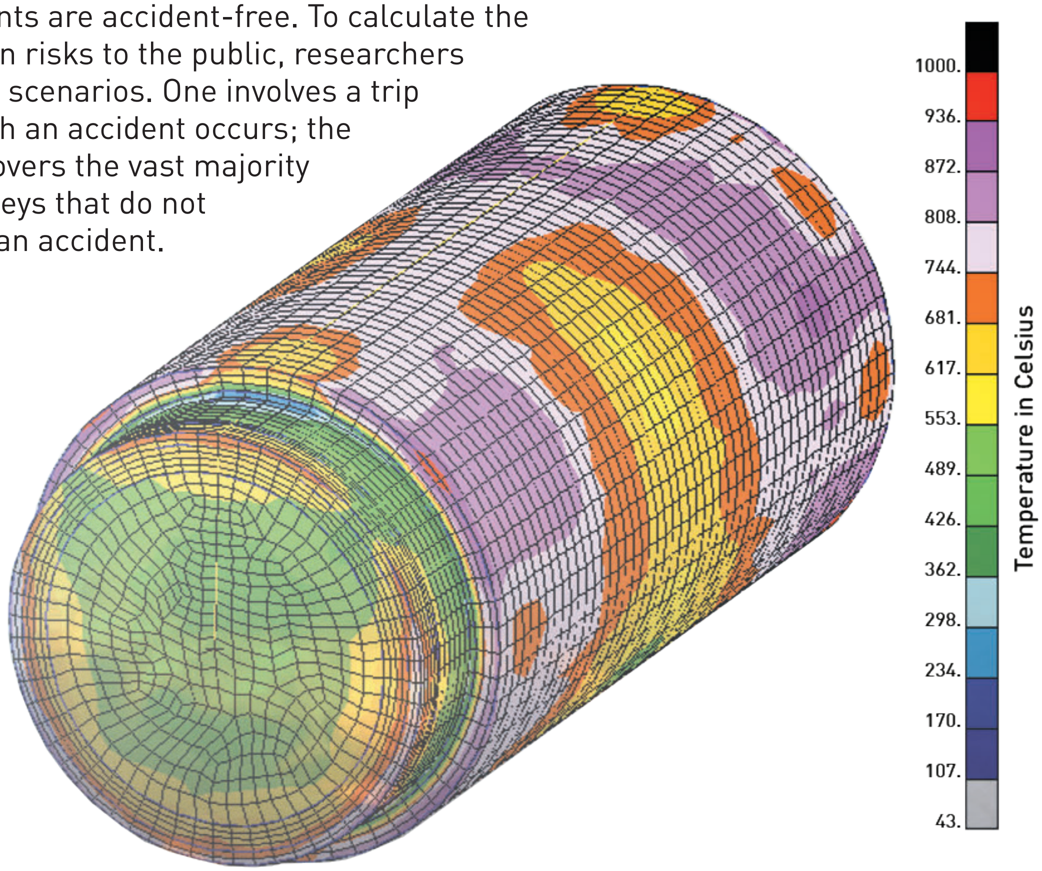
- **What can go wrong?**
- **How likely is it to occur?**
- **If something goes wrong, what are the consequences?**

The overwhelming majority of spent fuel shipments are accident-free. To calculate the radiation risks to the public, researchers use two scenarios. One involves a trip on which an accident occurs; the other covers the vast majority of journeys that do not involve an accident.

Researchers use a four-step process to study actual and potential accidents and their effects.

Step 1. Experts determine what might happen.

- *They gather historic records.*
- *They also put together data on how many spent fuel shipments are likely each year.*
- *They look at the rate of accidents for rail and highway shipments.*
- *They look at a large number of accidents that are credible.*
- *They also look at the effects of crash impact forces, fires, or punctures on the shipping container. They pick forces that are more severe than those covered by NRC standards.*



Shown is a computer simulation of the response of a cask to a severe fire environment. Analyses like this and tests are used by NRC to assure safe transportation of spent fuel.

Step 2. Engineers use complex computer programs to estimate how the parts of a shipping container might be damaged by collisions or fires.

- *They gather data on how much spent fuel each container will carry.*
- *They analyze how the spent fuel might respond in a given type of accident.*
- *They calculate the temperature of the container and the spent fuel itself during a long-term fire.*

This information allows engineers to estimate the size of a potential leak and how much nuclear material might escape.

Step 3. Researchers match accident scenarios from Step 1 with the analyses from Step 2. This tells them the likelihood that there would be severe damage to the container or its contents.

Step 4. A special computer program computes a risk estimate. The program takes accident probability estimates, expected numbers of shipments, route data (like population densities), weather data (to estimate how any release might be spread by wind), and radiological dose data to produce a risk estimate.

The Accident Scenario

NRC studies show the likelihood of a radioactive release is very low. Fewer than 5 in 10,000 accidents involving a spent fuel container may be more severe than the conditions defined in the design standards. We would not expect a radioactive release in 99.99973% of those 5 accidents. However, if a very unlikely chain of events occurs, an accident might be severe enough to cause a release.

To estimate the risk of these severe accidents, researchers use a multi-step approach. They use data and their experience with past highway and rail accidents involving other hazardous materials. Part of this step is to determine what kinds of accidents could happen and look at what their effects might be.

Using this method, the chance that an accident would be serious enough to lead to a release is 1 in 1 billion. If an accident did release radioactive material, the dose to the most affected individual would not cause immediate harm.

The Accident-Free Scenario

For most spent fuel shipments, nothing will go wrong and no nuclear material will be released. For these shipments, experts calculate the total radiation dose that all people along the route could receive. They use information on routes and local populations to determine how many people may be affected and the dose they could receive.

The risk to the public from an accident-free journey results from the very low levels of radiation that may come through the cask walls. A person standing along the highway or railroad track might receive a brief exposure that is well below regulatory limits. Exposure will vary depending upon the speed of the vehicle and how far away the person is standing. Doses from routine transport would be less than 1/1000 the amount of radiation people receive from background sources each year.

The Bottom Line

The NRC believes that shipments of spent fuel in the United States are safe. This belief is based on the NRC's confidence in the shipping containers that it certifies and its ongoing research in transportation safety.

- **The NRC ensures that shipping containers are robust by:**
  - Defining strict requirements for package design and performance
  - Reviewing designs and independently checking a container's ability to meet accident conditions
  - Doing inspections to ensure casks are built, maintained and used properly
- **The NRC also looks at the risks involved in spent fuel shipments. The agency:**
  - Analyzes spent fuel transport records to fully understand potential safety issues
  - Evaluates new transportation issues, such as projections for the number of shipments, changes in population along some routes, and other factors
  - Keeps up with technology as it evolves to refine estimates of current and future risk to the public

There will always be a slight chance that an accident will cause a release of nuclear material. But the NRC has found the likelihood of such an event and the risk to the public to be extremely low. Even so, the NRC will continue to be vigilant about public safety as an essential part of its mission.

Spent Fuel Transport Security

The NRC also regulates how spent nuclear fuel is protected in transit against sabotage or theft. The agency strengthened these rules after Sept. 11, 2001. The current rules for the physical protection of spent fuel transport include:

- **Coordinating with law enforcement agencies before the shipment**
- **Requiring advance notice to States, Indian tribes, and the NRC**
- **Using a communications center and other means to monitor shipments while in route**
- **Using armed escorts, and**
- **Using devices that allow drivers and escorts to immobilize the vehicle**

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