SPENT NUCLEAR FUEL PACKAGING, SHIPPING, AND STORAGE

PRESENTED TO THE
CONCERNED CITIZENS OF LAGUNA VILLAGE

BY

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BACKGROUND / BIO

- 43-year Career At General Atomics in three divisions
- 27 Years on the technical side –
  - Specialized in fabricating and testing unirradiated nuclear fuel and testing irradiated nuclear fuels
  - Spent 8 years decommissioning facilities used for researching unirradiated and irradiated nuclear fuels
  - Included packaging, storing, and shipping irradiated materials
- Most recent16 years in Nuclear Quality Assurance
  - Nuclear Quality Engineer
  - Lead Nuclear Auditor

SPENT NUCLEAR FUEL PRESENTATION TOPICS

- Energy Sources
- Electricity Production Method
- Fusion vs Fission
- Fission Products & Radioactive Decay
- Categories of nuclear fuel vs radioactive waste
- Advanced Reactors & Fuel Designs
- Packaging, shipping, & storing nuclear fuel
- US Government policies and plans pertaining to nuclear fuel storage

DEFINITIONS

- Fission
- Fissile vs Fertile materials
- Fusion
- Nuclear fuel
  - New
  - Spent/Used
- Radioactive
- Waste
  - Nuclear
  - Radioactive

Energy Sources

- Fossil Fuels – natural gas, oil, coal
- Nuclear
- Solar
- Wind
- Hydroelectric

- Electricity Production Method
  - All fuels are designed to produce heat, to boil water for making steam, the steam from the boiling water is used to power a turbine which spins a generator that produces electricity

NUCLEAR ENERGY

- Fusion vs Fission

- Fusion – thermonuclear fusion – is the joining of four hydrogen atoms to make helium, which releases energy in the form of heat

- Fission – the splitting of radioactive atoms to release energy in the form of heat

Fusion - The Sun

- Radius: 695,000 km (equator)
- Distance from Earth: 93,000,000 miles [1 astronomical unit (AU)]
- Takes 8.3 minutes for light to reach the earth
- Rotation period: 25 - 36 days
- Luminosity: 3.839×10^{26} watts
- Mass: 1.989×10^{30} kg
- Mean density: 1.410 gm/cm^3
- Surface temp: 5,780 K (mean)

FUSION - THE SUN

- Comprised of different layers with different properties
- Layers are composed of gaseous material that is about 75% hydrogen and 25% helium by mass
- The sun’s core:
  - Temperature is about 15 million Kelvin
  - Density is 150 times that of water
  - Pressure is over 200 billion times greater than earth’s atmospheric pressure
  - These conditions allow fusion to occur spontaneously

Fusion - The Sun - Thermonuclear Fusion

- In the sun's core hydrogen is converted into helium
- Four hydrogen atoms fuse into one helium atom. During the process some of the mass is converted into energy

Mass of 4 H atoms: 4.03130 AMU
mass of 1 he atom: 4.00268 AMU
1 atomic mass unit (AMU) equals $1.67 x 10^{-27}$kgs

The difference between the mass of 4 H atoms and 1 He atom is 0.02862 AMU is 0.71% of the original mass. This small fraction of the mass is converted into energy.

Fusion - The Sun

- If 4 grams (1/8 ounce) of H are converted to He, only $2.8x10^{-3}$ grams of the mass is converted to energy

- Using Einstein's formula, where c = the speed of light):

  $E = mc^2$

  $E = (2.8x10^{-3} \text{ grams}) \times c^2$

  $E = (2.8x10^{-6} \text{ kgs}) \times (3x10^8 \text{m/sec})^2$

  $E = 2.6x10^{11}$ joules

Enough energy to keep a 60-watt light bulb shining for over 100 years! Great promise! But still two decades away.

FUSION

- On earth, fusion technology uses isotopes of hydrogen
  - Deuterium, ^{2}H, abundant from seawater
  - Tritium, ^{3}H, obtained by irradiating Lithium
- Drawbacks - Takes more resources that the energy it yields
  - Electricity
  - Helium – for cryogenics
  - Reaction sustainability has not been possible

FISSION - DEFINITIONS

- Fission – the splitting of radioactive atoms to release energy
- Fissile vs Fertile materials
  - Fissile is a term used to describe an isotope that can undergo fission by thermal neutrons
  - Fertile is a term used to describe an isotope that cannot undergo fission by thermal neutrons

FISSION - DEFINITIONS

- Fissionable materials
  - ^{235}Uranium is the only naturally occurring, fissionable isotope

  - ^{239}Plutonium and ^{233}Uranium, are artificially produced from the fertile materials, ^{238}Uranium and ^{232}Thorium, respectively

FISSION

- Natural, mined uranium contains ~ 99.3% ^{238}U, 0.72% ^{235}U, and < 0.01% ^{234}U
- These three naturally occurring uranium isotopes are physically separated using one of two methods – gaseous diffusion or gas centrifuge
- The ^{235}U is collected and consolidated
- The resulting mixture is used as nuclear reactor fuel

FISSION

- Common ^{235}U fuel enrichments
  - Commercial reactors use 3 – 5 weight %
  - San Onofre **4.8 WEIGHT PERCENT**
  - Research reactors 19.7% (TRIGAs, etc., LEU)
  - Weapons grade 90%+ (HEU)
  - Navy nuclear 93.5% (HEU)

- GTRI of May 2014 aimed at minimizing as quickly as possible the amount of nuclear material available that could be used for nuclear weapons, $\geq$ HEU to LEU

FISSION

- When ^{235}Uranium is bombarded with neutrons, the uranium atoms split, releasing more neutrons, heat, and atoms with smaller atomic numbers
- The radiation emitted is in the form of alpha and beta particles and gamma rays
- During fission, some ^{235}Uranium atoms capture neutrons to form heavier radioactive elements (known as transuranic elements), such as plutonium and neptunium

FISSION

- The byproducts of fission are highly radioactive, with long half-lives (e.g., ^{129}Iodine, ^{137}Cesium, ^{90}Strontium, ^{99}Technetium, and ^{239}Plutonium)

- Primary reason that spent fuel is significantly more hazardous than the original unreacted fuel rod

- Stabilizing SNF methods including vitrification in glass, ceramics, and advanced storage cask technology.

Categories of Nuclear Fuel vs Radioactive Waste

Categories of nuclear fuel

- Fresh fuel - unirradiated
- Spent nuclear fuel – used but still good
- Radioactive waste – materials for which there is no further use

SPENT NUCLEAR FUEL

- Spent Nuclear Fuel (SNF) is used fuel
- It is NOT waste
- More than 90% of SNF’s potential energy still remains in the fuel, even after five years of operation in a reactor.
- SNF is recyclable to make new fuel and byproducts.

SMALL MODULAR REACTORS (SMRS)

- Small modular reactors (SMRS) are defined as nuclear reactors generally 300 MWe equivalent or less
- SMRs can be placed with one or more units to meet the local electrical needs
- Designed using module factory fabrication techniques, pursuing economies of series production and short construction times

SMALL MODULAR REACTORS (SMRS

- SMR designs may employ light water as a coolant or other coolants such as a gas, liquid metal, or molten salt

- There are three varieties of light-water reactors:
  - pressurized water reactor (PWR)
  - boiling water reactor (BWR)
  - Supercritical water reactor (SCWR).

FUTURE USES FOR SPENT NUCLEAR FUEL

- There are some advanced reactor designs in development that could run on spent nuclear fuel in the future
- SMALL MODULAR REACTORS
- GENERATION IV NUCLEAR REACTORS
  - Sodium-cooled fast reactor
  - Very High Temperature Reactors, graphite-moderated, He-cooled
  - Molten Salt

SMR COMPANIES

- NuScale Power, LLC – first to have its reactor design approved by the NRC
  - Multi-application small light water reactor," 50 MW per module
  - Uses water both as a coolant and neutron moderator
- Terrapower – molten chloride fast reactor, financed by Bill Gates

SMR COMPANIES

- Moltex Energy (Canada), Moltex's stable salt reactor – waste burner (SSR-W) uses SNF
- Passively safe - no human intervention is required to shut it down in the event of a problem.
- There is no contained pressure in the reactor because everything happens at atmospheric pressure; and
- The fission reaction slows down as the temperature rises, so the system is self-damping.

SMR COMPANIES

- Terrestrial Energy inc. INTEGRAL MOLTEN SALT REACTOR (IMSR®), 400MW

- General Atomics/Framatome – helium-cooled 50-megawatt electric (MWe), fast modular reactor

- GE Hitachi Nuclear Energy (US), BWRX-300, boiling water reactor (BWR)
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SMALL MODULAR REACTORS - BENEFITS

- Manufactured under factory conditions
- Reduced on-site construction costs
- Increase operation efficiency
- Containment efficiency
- Enhanced safety through passive safety features
- No need to install by a major water supply

SMR PASSIVE SAFETY FEATURES

- Don’t require any safety-related electric pumps or operator intervention to safely shut down.
- Auxiliary cooling systems are capable of 100% core heat removal via natural circulation

Packaging, Shipping, & Storing Spent Nuclear Fuel

- Spent Nuclear Fuel (SNF) is packaged for both storage and shipping purposes
- Both the storage and shipping of SNF must follow specific safety requirements
- The Department of Transportation controls the packaging of radioactive materials for shipping purposes

DRY FUEL STORAGE AT SONGS

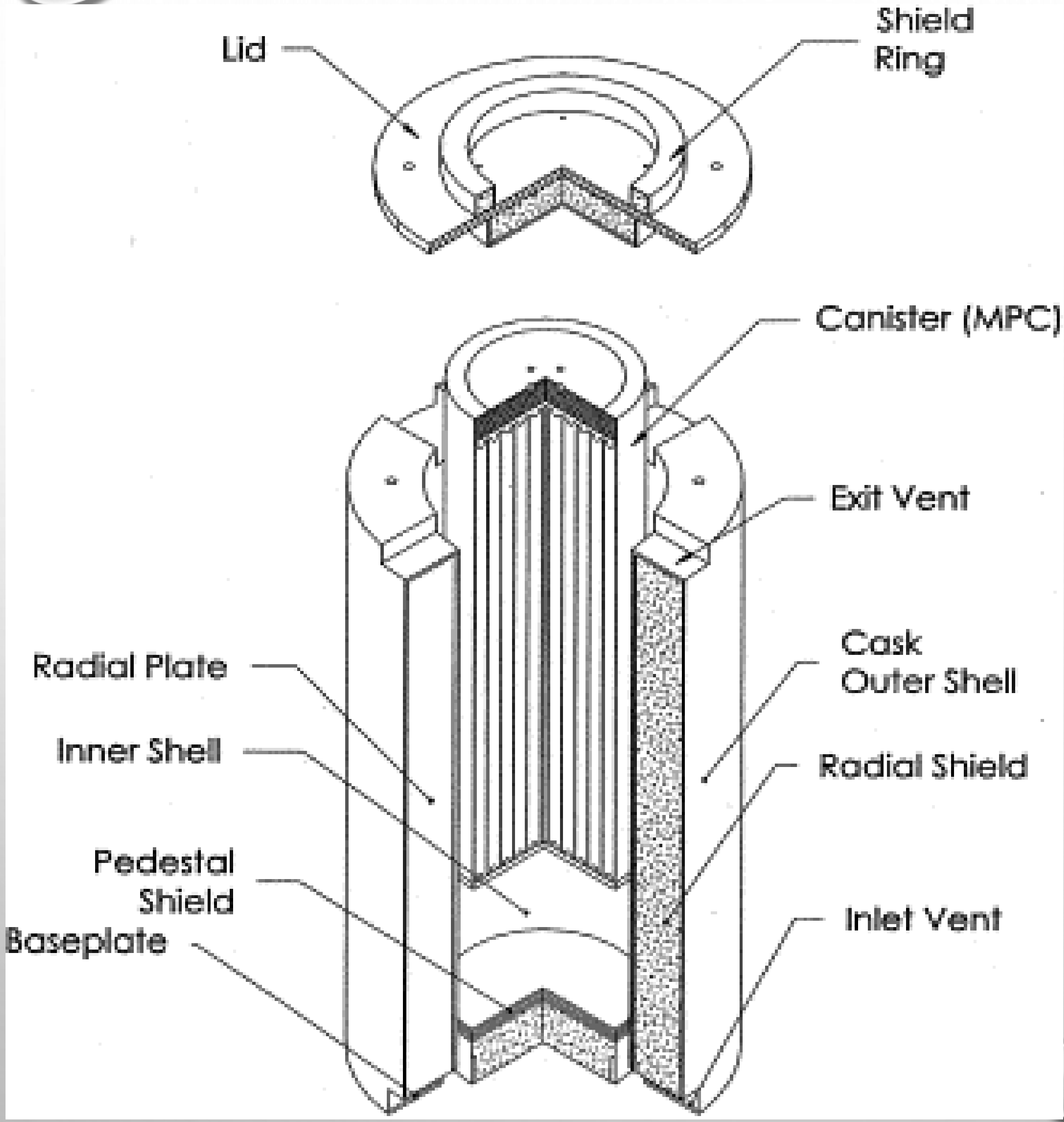
- San Onofre has two systems for dry fuel storage
- The first is an ORANO-NUHOMS horizontal storage system
  - SCE began loading fuel into this system from Units 1, 2 and 3 in 2003
  - It holds 50 canisters of spent fuel
- The second system is the HOLTEC UMAX system.
  - SCE has completed loading fuel into this system
  - It holds 73 canisters of spent fuel from Units 2 and 3

SONGS SNF DRY STORAGE CANISTERS

- ORANO is the manufacturer of the TN-NUHOMS dry fuel storage system at SONGS,
- The spent nuclear fuel storage canisters at SONGS have a service life of 100 years or more.
- According to NRC-analyzed accident scenarios, using dry storage systems, vs pools of actively-cooled water, the number of events that can result in an offsite release of radiological material *drops to zero.*

DRY STORAGE CANISTERS

- Spent nuclear fuel is sealed in airtight, welded steel canisters that provide both structural strength and shielding,
- Sealed canisters are housed in reinforced concrete structures.
- Dry fuel storage involves a passive cooling system with no moving parts
- Inside the canisters is helium, an inert gas that helps with the cooling process.
- Heat from the fuel is dissipated by air entering vents in the storage structure and circulating around the outside of the steel canister.



HI-STORM® dry storage cask system for spent nuclear fuel (courtesy of Holtec International;

PERIODIC INSPECTIONS OF THE SNF DSC

- A key aspect of maintaining that longevity of safety is to conduct periodic inspections of the exterior of the canisters, as well as the concrete storage modules
- These inspections are part of what's called an aging management program approved by the NRC
- SCE and recently conducted the baseline inspections
- The inspections found no signs of degradation of the inspected canisters, which have been in storage 17 and 18 years

SONGS FINAL PLAN WILL BE THREE DOCUMENTS

- **STRATEGIC PLAN FOR DISPOSITION OF SONGS SNF**
  - Addresses alternative pathways and offers findings regarding the offsite relocation of SONGS SNF
- **SONGS SNF CONCEPTUAL TRANSPORTATION PLAN**
  - Identifies on-site preparations needed to prepare SONGS SNF for transport
- **SCE ACTION PLAN**
  - Outlines follow-up steps by SCE to catalyze action based on findings in the strategic and conceptual transportation plans

Locations of Low-level Waste Disposal Facilities

- The four active, licensed low-level waste disposal facilities are located in agreement states (Additional information about the facilities may be found at the web sites maintained by the respective agreement states)

- **Energy Solutions Barnwell operations, located in Barnwell, South Carolina** currently, Barnwell accepts waste from the Atlantic Compact states (Connecticut, New Jersey, and South Carolina). Barnwell is licensed by the state of South Carolina to dispose of Class A, B, and C waste.

- **Energy Solutions Clive operations, located in Clive, Utah** Clive accepts waste from all regions of the United States. Clive is licensed by the state of Utah for Class A waste only.

Locations of Low-level Waste Disposal Facilities (Continued)

- **U.S. Ecology, located in Richland, Washington** Richland accepts waste from the northwest and rocky mountain compacts. Richland is licensed by the state of Washington to dispose of Class A, B, and C waste.

- **Waste Control Specialists (WCS), LLC, located near Andrews, Texas**
  WCS accepts waste from the Texas Compact generators and outside generators with permission from the compact. WCS is licensed by the state of Texas to dispose of Class A, B, and C waste.

THERE IS NO NATIONAL LONG-TERM STORAGE SITE FOR SPENT NUCLEAR FUEL

- The US government DOE-operated disposal sites for government waste
  - Hanford
  - Nevada National Security Site (formerly NTS)
  - Military only - WIPP
    - The Waste Isolation Pilot Plant is the nation’s only deep geological repository site for disposal of defense-generated TRU waste from DOE sites

Commercial Spent Nuclear Fuel: Congressional Action Needed To Break Impasse and Develop A Permanent Disposal Solution
GAO-21-603, Published & Publicly Released: Sept, 23, 2021.

Recommendations to Congress:

1. Amend the Nuclear Waste Policy Act to authorize a new consent-based process for siting, developing, and constructing consolidated interim storage and permanent repository facilities for commercial spent nuclear fuel

2. Create a mechanism, such as an independent board, to provide political insulation and continuity of leadership for managing the spent nuclear fuel disposal program.

Commercial Spent Nuclear Fuel: Congressional Action Needed To Break Impasse and Develop A Permanent Disposal Solution
GAO-21-603, Published & Publicly released: Sept. 23, 2021

Recommendations to Congress (Continued)

3. Restructure the Nuclear Waste Fund so funds used to develop, construct, and operate a permanent repository are based on the commercial spent nuclear fuel program's life cycle costs.

4. Direct the DOE to develop and implement an integrated waste management strategy, consistent with any amendments to the Nuclear Waste Policy Act, that includes plans for the transportation, interim storage, and permanent disposal of spent nuclear fuel.

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QUESTIONS?