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Savannah River Site Legacy Heavy Water Detritiation

Dave Babineau, Lucas Angelette, Cale Gustafson

Citizens Advisory Board

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U.S. DEPARTMENT of ENERGY

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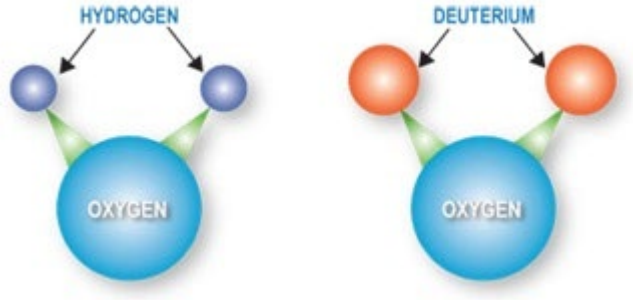
BSRA Battelle Savannah River Alliance, LLC

Heavy Water

- Heavy water/deuterium is used in numerous applications
  - Pharmaceuticals
  - Semiconductors
  - Chemical Industry
  - Medical Imaging
  - Nuclear fission and fusion reactors
  - Nuclear weapons



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- Heavy water can be electrolyzed to make deuterium gas
  - Easier to store and transport water than gas
- Bottom Line – SRS Legacy Heavy Water has significant *potential* commercial value

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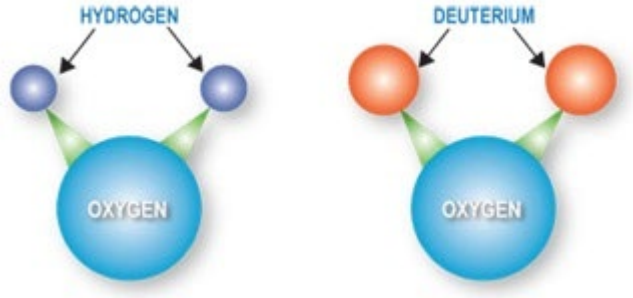

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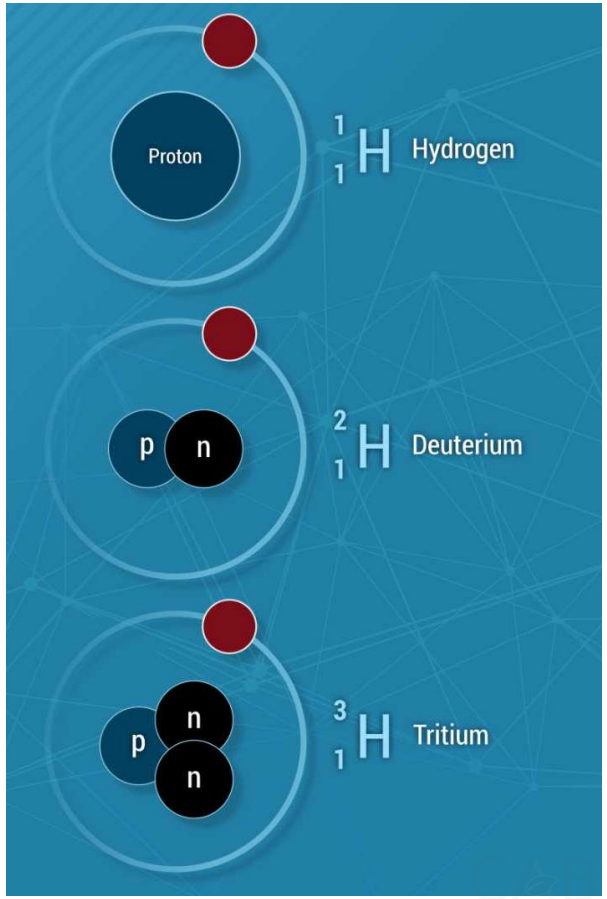
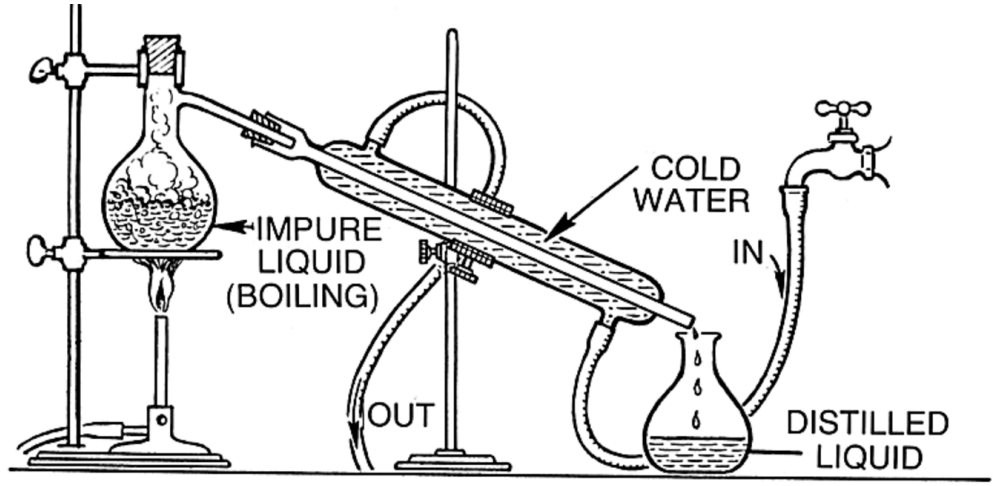
Hydrogen Isotopes

- Isotope – atoms with the same number of protons but different numbers of neutrons
  - Isotopes of the same element behave almost identical
- Hydrogen exists as three different isotopes
  - Protium – regular hydrogen (1 proton, 1 electron)
  - Deuterium – “heavy” hydrogen (1 proton, 1 neutron, 1 electron)
  - Tritium – radioactive hydrogen (1 proton, 2 neutrons, 1 electron)
- Water can exist with all three hydrogen isotopes
  - Regular water is H_2O
  - Heavy water is D_2O
  - T_2O can exist, but will equilibrate with atmospheric humidity



Making Heavy Water

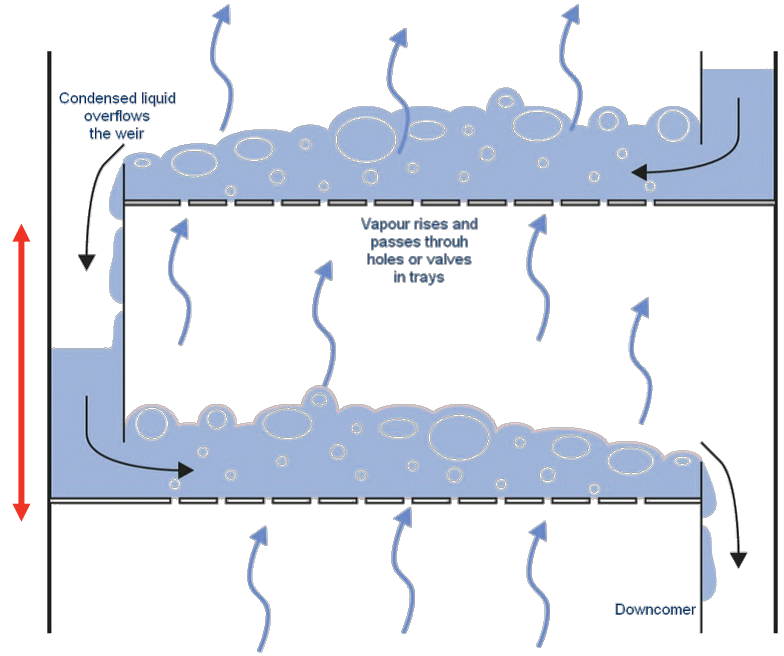
- Deuterium is naturally present in all water
  - Approximately 150 deuterium atoms for every 1 million hydrogen atoms
    - Termed as parts-per-million
- To concentrate the deuterium, the water is distilled
  - Heavy water and normal water have slightly different boiling points
    - Normal water – 212°F
    - Heavy water – 214.5°F
  - Normal water evaporates faster
    - Heavy water concentrates in the liquid



Simple illustration of distillation

Making Heavy Water

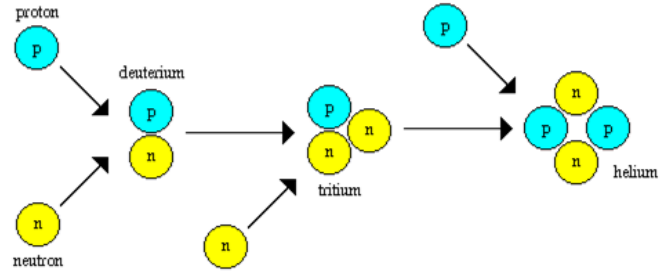
- Distillation is based on boiling a liquid to separate out different components
  - Vapor concentrates the lighter component (hydrogen)
  - Liquid concentrates the heavier component (deuterium)
- Water distillation occurs under vacuum
  - Between 1/10th to 1/3rd of atmospheric pressure
    100°F 150°F
- Deuterium concentrates ~6% per stage
  - 150 parts-per-million → 159 parts-per-million in 1 stage
  - Need hundreds of stages
  - Going from 0.015% to 99.8%



Simplified illustration of a single distillation stage

Detritiation

- Heavy water used in nuclear reactors will make tritiated water
  - Tritiated water – water with tritium (radioactive hydrogen)
  - Formed by absorbing neutrons from nuclear reactors



- In order for the heavy water to be reused, the tritium must be removed
  - SRS heavy water is between 0.2 - 1 Curies / kilogram (0.9 liter)
    - Typical medical imaging procedure utilizes Tc-99m, at 5 to 30 millicuries
    - Equal to 200,000 – 1,000,000 microCuries / kilogram
    - Virgin heavy water is 2 microCuries / kilogram
    - Factor of 500,000 reduction at 6% per distillation stage
    - Feed water will run through filtration system to remove residual radionuclides, solvents, particulates, and other “junk”

Technological Selection

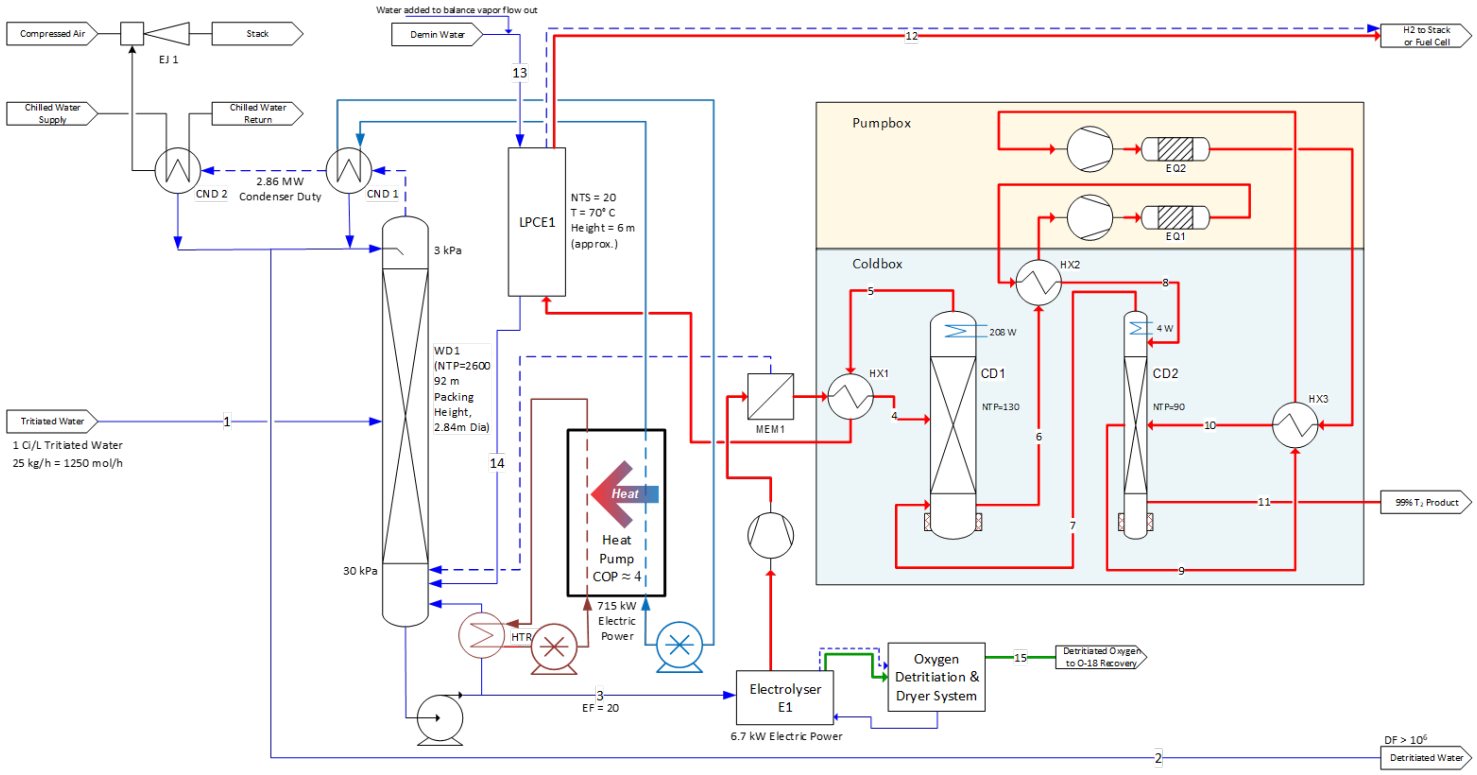
- Water distillation
  - 95% volume reduction
    - Approximately 540,000 gallons → 27,000 gallons in storage
    - Approximately 400,000 gallons of heavy water, rest as light water
    - Tritium concentration increases 20x in tritiated effluent

- Water distillation with catalytic exchange and cryogenic distillation
    - Catalytic exchange – catalyst promotes isotopic exchange between water and electrolyzed hydrogen
  - 100% volume treatment
  - 382,000 gallons of heavy water recovered
  - Tritium can be collected and used for scientific research (fusion, medical, etc.)
- Both options based on similar practices to be used in Canada and Romania

Water Distillation with Catalytic Exchange and Cryogenic Distillation – Full-Scale

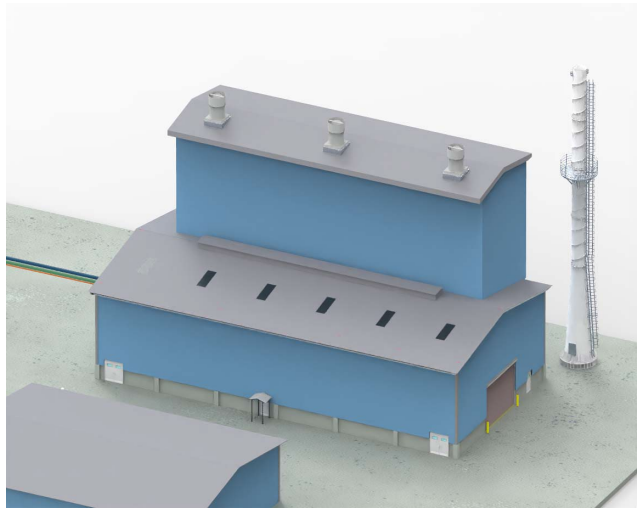
- 300 vertical feet for primary detritiation column
  - Split between multiple columns in series
- 20 vertical feet to reach 99.8% isotopic purity
  - Must electrolyze that portion of water
  - Hydrogen isotopes can be distilled at ultra-low temperatures
  - Will result in little to no liquid waste that requires disposition
- Can process entire Savannah River Site inventory in 10 years

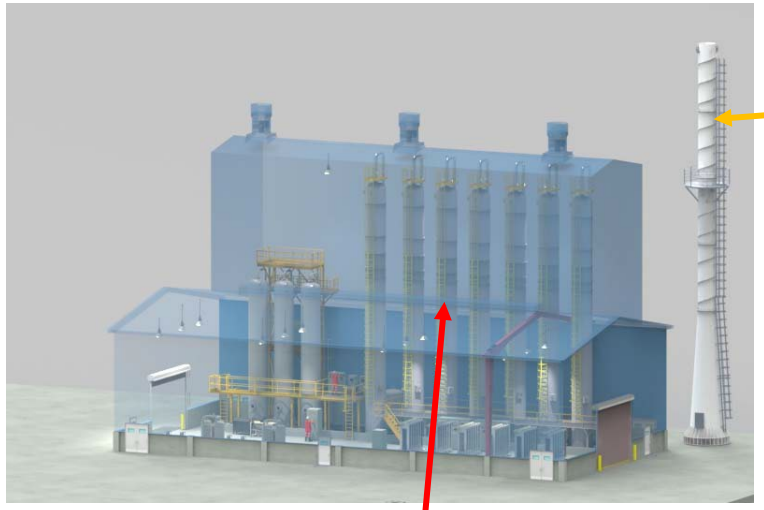
- Water distillation alone can achieve separation if a lower budget is required
  - Will result in 27,000 gallons of heavy water with higher tritium content
  - Will need to grout or continue storing



Heavy Water Detritiation Plant – Notional Layout

Footprint on order of 10,000 square feet





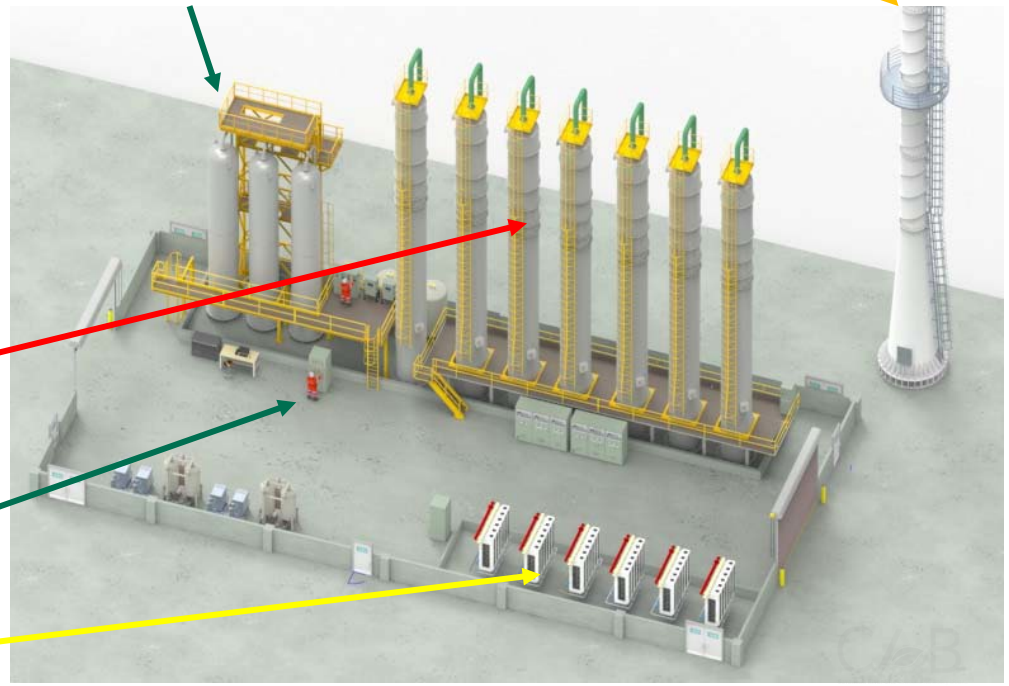
Cryogenic distillation

Catalytic exchange columns

Water distillation equipment

Worker for scale

Electrolyzers



Heavy Water Detritiation Demonstration Plant

- No current technology proven for reducing tritium content to the extent needed
  - Typically used to decrease tritium from 20 Curies/Liter to 1 Curie/Liter in heavy water reactors
  - Considered for light water detritiation to required levels, but not heavy water to date
  - Best option is water distillation, either with or without catalytic exchange and cryogenic distillation

- Demonstration needed to verify feasibility before pilot- or full-scale design and implementation

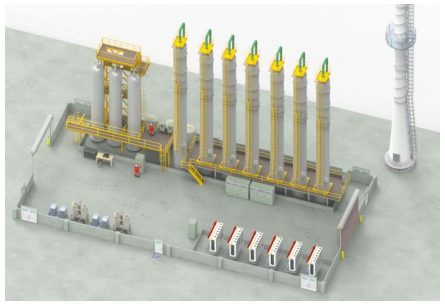
- Cost estimate developed for 1/80th scale demonstration plant
  - Equivalent to 300 grams/hour feed rate
  - 0.075 gallons (1.2 cups) per hour
  - 520 gallons per year

Demonstration Scale

- Department of Energy Office of Science Isotope Program requested demonstration scale system
  - Prove distillation can reduce tritium levels down to virgin heavy water
  - Within the established funding levels
- Demonstration scale system
  - 4 inch diameter column
  - 100 feet total length
  - Set of four columns 25 feet tall
  - Batch distillation
  - Production rate is 3.2% of feed rate
    - 300 grams per hour feed = 9.6 grams commercial D_2O produced
    - Smaller columns are less efficient, but can still prove the principle

Demonstration Scale

- Existing structures are expensive to renovate
- All scales going forward will be considered for external operation
  - Standard industrial practice (i.e. Canada and others)
  - Radiation Protection has evaluated external operations with no identified concerns
  - Environmental Protection identified secondary confinement mitigation needed for potential liquid migrating beyond process footprint (accident scenario)
  - Minimizes facility construction cost associated with process plant equipment
  - Reduces construction to control room structure/office
  - Electrical equipment can be built in weatherproof cabinets
  - Numerous concrete slabs exist from previously demolished facilities



Questions?