CONVENTIONAL NUCLEAR REACTORS

DIRTY NUCLEAR REACTORS

OUTLINE

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- HOW A REACTOR WORKS
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- REACTOR TYPES
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  - BWR
  - CANDU
  - UKRAINE
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- WASTE
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  - LLW

SCIENCE

ISOTOPES – VARIATIONS IN ATOMIC NUMBER

CARBON DATING - ^{14}C RADIOACTIVE, NORMAL ISOTOPE ^{12}C

RATIO OF RADIOACTIVE TO NORMAL DETERMINES AGE

SO U HAS TWO PRINCIPAL ISOTOPES ^{238}U AND ^{235}U - MASS NUMBER (A) 238 AND 235

SCIENCE

^{238}U ABOUT 97.3% ABOUT 0.7% ^{235}U.

NORMAL FISSON IN THERMAL (CONVENTIONAL) WITH ^{235}U, SO THERE IS HUGE WASTAGE OF - A FUEL MODERATOR IS USUALLY ADDED SO THAT THE NEUTRON ARE SLOWED SUFFIENT TO CAUSE THE ^{235}U TO FISSON,

MODERATOR IS USUALLY WATER OR GRAPHITE

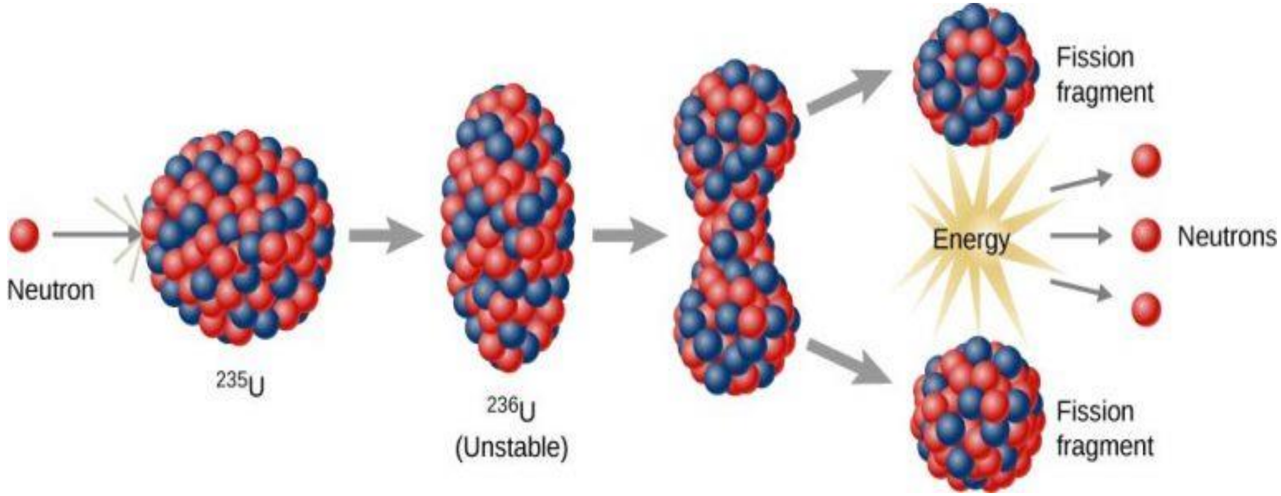
IN FAST REACTORS, COOLED WITH LIQUID METAL OR MOLEN SALT

NEUTRONS CAN UNLOCK THE ENERGY IN THE DOMINANT ISOTOPE OF URANIUM (^{238}U)

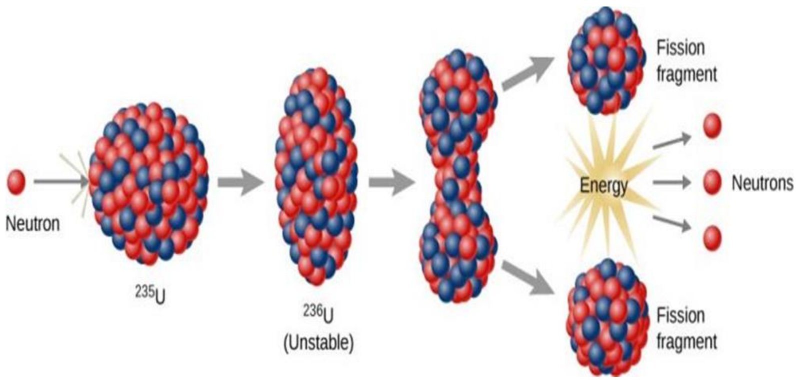
THUS EXTEND KNOWN FUEL RESOURCES BY AROUND 200X.

AVERAGE THERMAL NEUTRON MOVES AROUND AT ABOUT 2200 M/S WHILE A FAST NEUTRON MIGHT BE CRUISING WELL ABOVE 9 MILLION M/S, WHICH IS ABOUT 3% OF THE SPEED OF LIGHT.

NUCLEAR REACTION



NUCLEAR REACTION



- $^{235}U + n \rightarrow {}^{236}U \rightarrow {}^{140}Xe + {}^{94}Sr + 2n$
- Highly radioactive, the xenon decays with a half-life of 14 seconds and finally produces the stable isotope cerium-140.
- Strontium-94 decays with a half-life of 75 seconds, finally producing the stable isotope zirconium-94. .

SCIENCE

- CONTROL RODS
- NEEDED TO CONTROL THE FLUX OF NEUTRONS – BOTH IN FAST AND CONVENTIONAL
- HIGH NEUTRON CAPTURE CROSS-SECTIONS INCLUDE BORON, SILVER, INDIUM, AND CADMIUM AND MANY OTHERS

DISADVANTAGES

- HUGE COST BUILDING COST
- COST ANYWHERE BETWEEN €190-375/MWh 900% HIGHER THAN THE PUBLISHED LEVELISED COST OF ELECTRICTY (LCOE) OF €30/MWh FOR AN ACTUAL EXISTING OLKILUOTO NUCLEAR PLANT
- NON RENEWABLE
- RADIATION - WASTE
- NUCLEAR PLANT ACCIDENTS
  - THREE MILE ISLAND (Failure of automatic valve triggering loss of coolant – no emission of radioactivity). Containment building sufficently strong.
  - CHERNOYBL (The accident occurred during a safety test on the steam turbine of an RBMK-type nuclear reactor**. Positive void coefficient** – cooling (water) moderator (graphite). See next slide.
  - FUKUSIHMA (Tsunami – unplanned event).

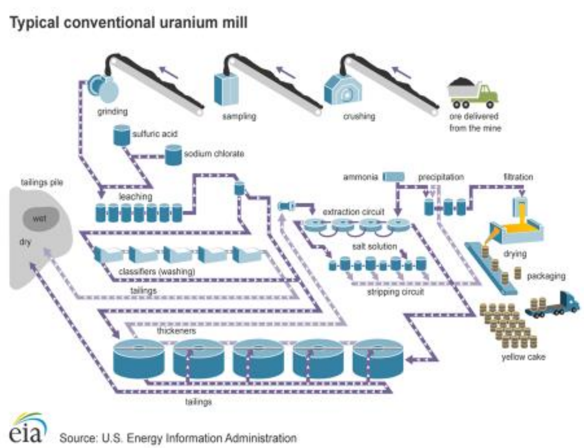
CHERNOBYL

- The term '**positive void coefficient**' is often associated with RBMK reactors – **different coolants and moderators**
  - Because water is both a more efficient coolant and a more effective neutron absorber than steam, a change in the proportion of steam bubbles, or 'voids', in the coolant will result in a change in core reactivity – **negative void**
- This leads to a reduction in power, and is a basic safety feature of most Western reactors.
- In reactor designs where **the moderator and coolant are of different materials**, excess steam reduces the cooling of the reactor, but as the moderator remains intact and the nuclear chain reaction continues.
- In such cases, the reduction in neutron absorption as a result of steam production, and the consequent presence of extra free neutrons, enhances the chain reaction. This leads to an increase in the reactivity of the system – **positive void**
- **Can be avoided by pushing in the control rods**

ADVANTAGES

- NON FOSSIL
- CLIMATE CHANGE

FUEL PROCESSING



Uranium dioxide (UO2) concentrate from mining

Thousand as radioactive as the granite used in buildings.

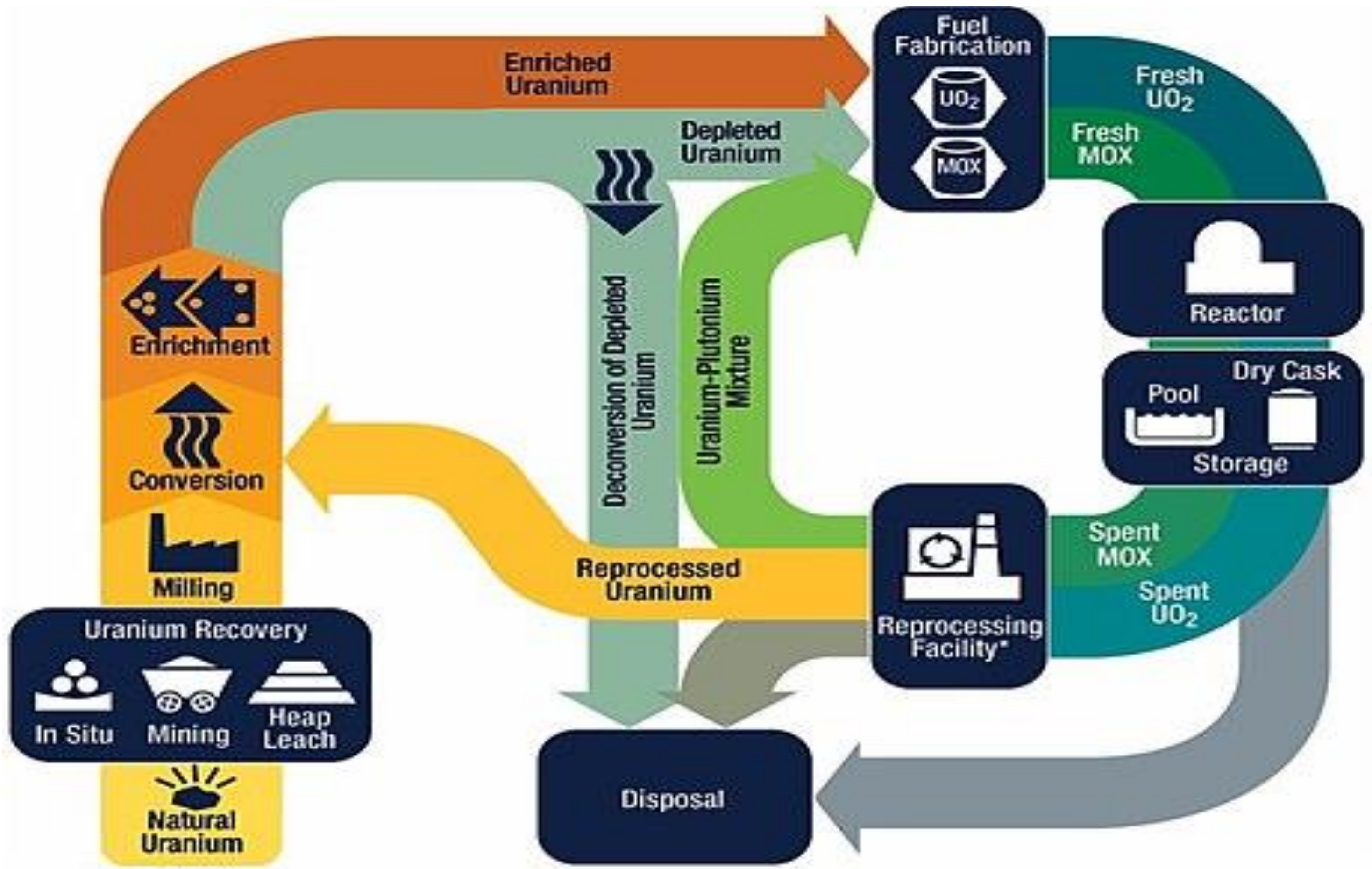
It is refined from yellowcake (U3O8),

converted to uranium hexafluoride gas (UF6). -   a gas,

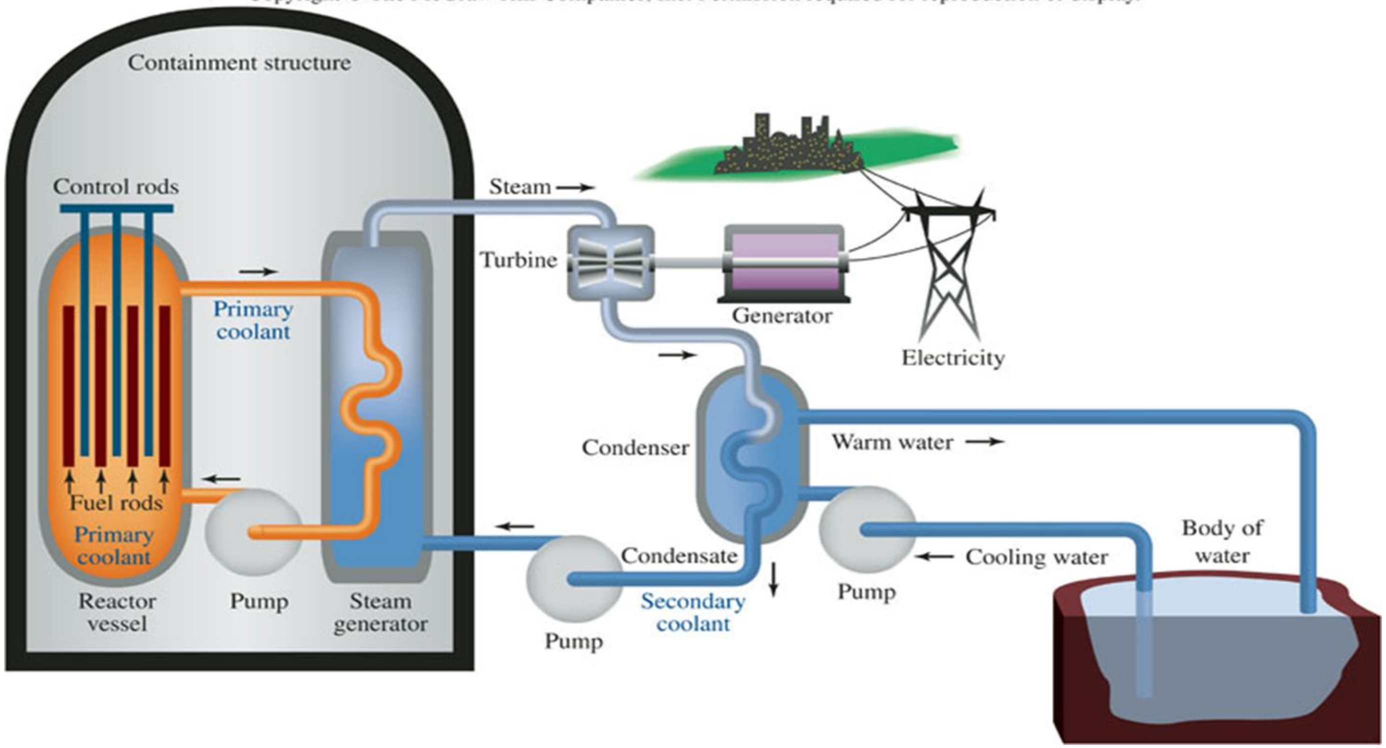
It undergoes enrichment to increase the U-235 content from 0.7% .

It is then turned into a hard ceramic oxide (UO2) (MOX) for assembly as reactor fuel elements.

FUEL CYCLE


Enriched Uranium
Depleted Uranium
Fuel Fabrication
UO2
MOX
Fresh UO2
Fresh MOX
Reactor
Dry Cask
Pool
Storage
Spent MOX
Spent UO2
Reprocessing Facility*
Reprocessed Uranium
Deconversion of Depleted Uranium
Uranium-Plutonium Mixture
Enrichment
Conversion
Milling
Uranium Recovery
In Situ
Mining
Heap Leach
Natural Uranium
Disposal

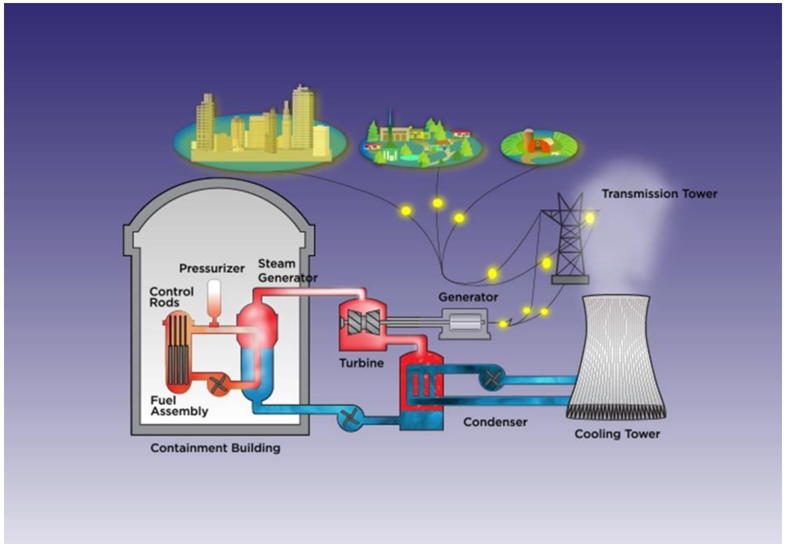
HOW A REACTOR WORKS



MODERATORS

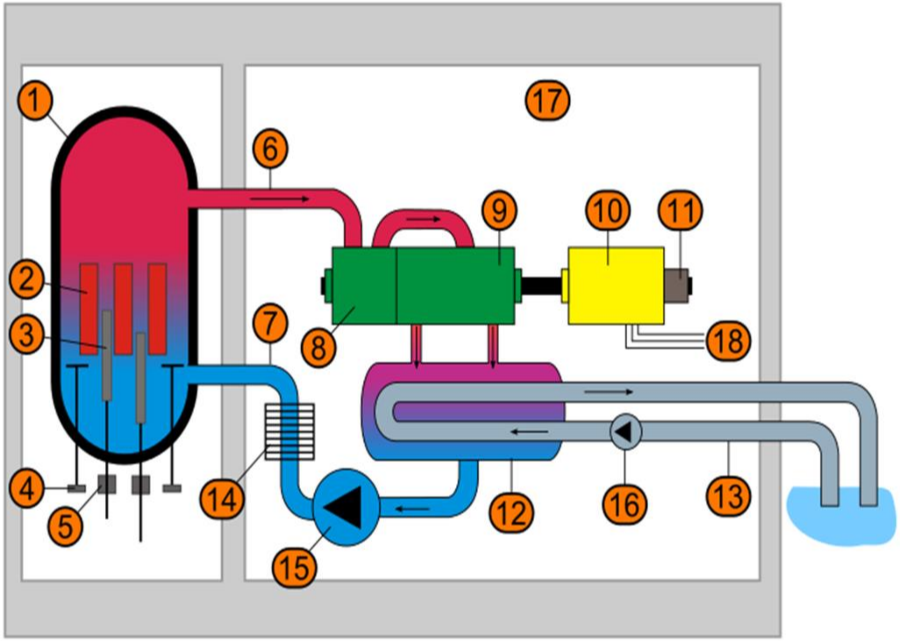
- GRAPHITE (AGR's IN THE UK AND OTHERS)
- WATER
  - BOILING WATER (BWR)
  - PRESSURIZED WATER (PWR)
    - Large majority worldwide
    - A primary characteristic of PWRs is a pressurizer, a specialized pressure vessel.

PRESSURISED WATER REACTOR (PWR)



- 155 bar (15.5 MPa) and 345 °C (653°F),
- As 345 °C is the boiling point of water at 155 bar
- The liquid water is at the edge of a phase change.
- Large reactors would have about 150–250 such assemblies with 80–100 tons of uranium in all.
- A PWR produces on the order of 900 to 1,600 MWe. PWR fuel bundles are about 4 meters in length.
- Re-fuelings for most commercial PWRs is on an 18–24 month cycle.
- Boric acid is often added as an extra moderator – no need to use control rods

BOILING WATER REACTOR (BWR)



- A boiling water reactor uses demineralized water as a coolant and neutron moderator.
- Operates at 75 bar (7.6 MPa)
- Heat is produced by nuclear fission in the reactor core, and this causes the cooling water to boil, producing steam.
- The steam is directly used to drive a turbine
- Condensed.
- Back to cool the reactor.

CANDU

- OPERATES ON NATURAL URANIUM (^{238} U)
- HEAVY WATER AS MODERATOR (D_2O)
- MAJOR ADVANTAGE AS FUEL PROCESSING ELIMINATED
- FIRST DEVEOPLED IN CANADA – USED WORLDWIDE

ZAPORIZHZHIA

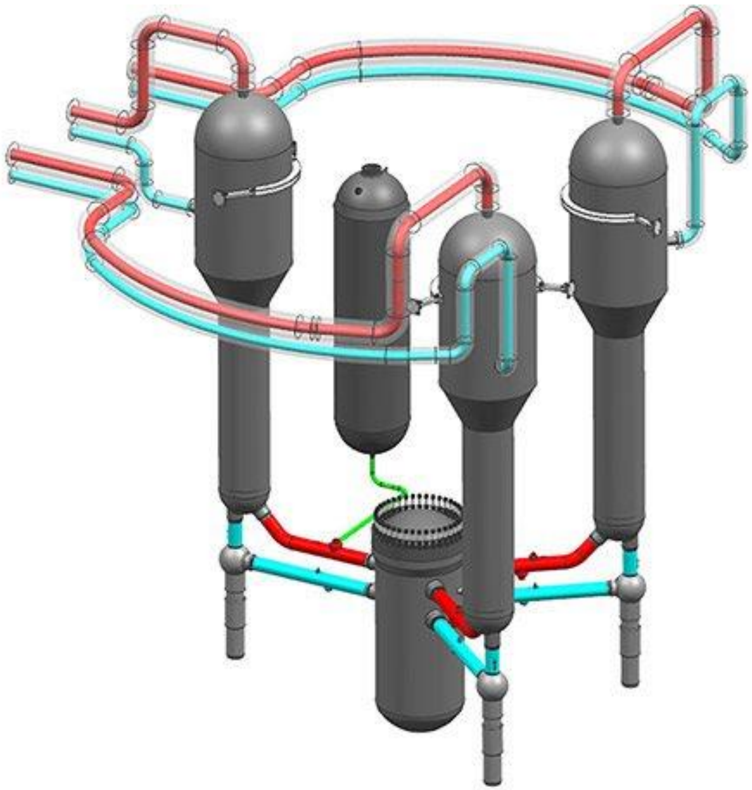
A PWR **– TOTAL POWER 5700 MW_e**

- 6 UNITS – EACH 960 Mw_e
- LARGEST IN EUROPE
- LAST UNIT COMMISSIONED IN 1996
- CAPTURED BY RUSSIAN INVASION OF UKRAINE?
- NO DAMAGE
- DID HAVE AN INCIDENT – SHORT CIRCUIT – LED TO BACKOUTS IN 2014

SMALL MODULAR REACTORS (SMRs)

- UP TO 3/400 MW_E
- CHEAPER IN THE LONG TERM – £60 per MWh PRESENTLY MORE EXPENSIVE THAN CONVENTIONAL
- STILL A PROBLEM WITH WASTE BUT?
- CAN BE REFUELED ONCE EVERY 20 YEARS
- CAN BE BUILT WHERE EXISTING LARGE PLANTS CAN'T
- PASSIVE SAFETY FEATURES DESIGNED TO SHUT THE PLANT DOWN AUTOMATICALLY - FOR 7 DAYS
- ROLLS ROYCE USES PWR TECHNOLOGY – AS USED IN SUBMARINES – 60 YEARS LIFE
- AN SMR POWER STATION IS SMALL ENOUGH TO FIT INSIDE WEMBLEY STADIUM.
- THE LEVELISED COST WILL BE JUST £60 PER MWH.

SMRs Advantages



The compact architecture enables modularity - implementation of higher quality standards.

Smaller reactors

Potential for sub-grade (underground or underwater) location of the reactor unit providing more protection from natural (e.g. seismic or tsunami according to the location) or man-made (e.g. aircraft impact) hazards.

The modular design and small size lends itself to having multiple units on the same site.

Lower requirement for access to cooling water – therefore suitable for remote regions and for specific applications such as mining or desalination.

Ability to remove reactor module or in-situ decommissioning at the end of the lifetime.

SMRs OTHER ADVANTAGES

- DISTRICT HEATING
- DESALINATION
- CHEMICAL PROCESS HEAT
- CAN BE SITED AT EXISTING DEFUNCT FOSSIL FUEL PLANT – ALL THE INFRASTRUCTURE IN PLACE

SMR TYPES

INTEGRATED PRESSURISED WATER REACTOR

Integrated Pressurised Water Reactors (IPWRs) offer a step change in the plant design approach from the conventional large nuclear Pressurised Water Reactors (PWRs);

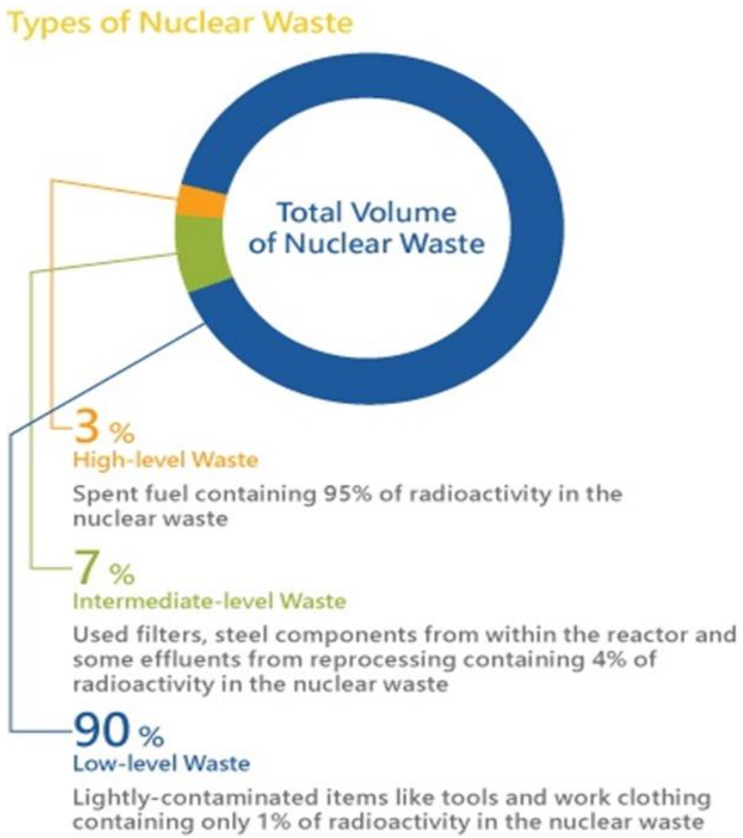
The IPWR incorporates the entire primary circuit into the Reactor Pressure Vessel (RPV). This offers the opportunity to remove the requirement for the large bore primary pipework and significantly reduces the risk of loss of coolant accidents.

The Steam Generators (SGs), Pressuriser and Primary Coolant Pumps (PCPs) are all housed within the RPV offering considerable space savings when designing the primary containment building.

SMR TYPES

- HIGH TEMPERATURE GAS COOLED REACTOR
- High Temperature Gas Cooled Reactors (HTGRs) are a type of thermal reactor, in which nitrogen or helium is typically used as the reactor coolant, with a graphite moderator.
- They operate at high temperatures, usually between 700-950°C, but can be in excess of 1000°C.
- High temperature operation is permitted by containing fuel in Tristructural-Isotropic (TRISO) particles with fissile material surrounded by three ceramic layers of pyrocarbon and silicon carbide.
- TRISO particles are embedded into a graphite matrix and formed into either graphite pebbles or graphite blocks with the graphite providing part of or all of the neutron moderation required. Key advantages of HTGRs include the ability to provide process heat to a greater range of industrial applications due to the high process heat temperatures (relative to other nuclear technologies).
- The use of TRISO fuel introduces an additional barrier to the release of radioactive materials to the environment.

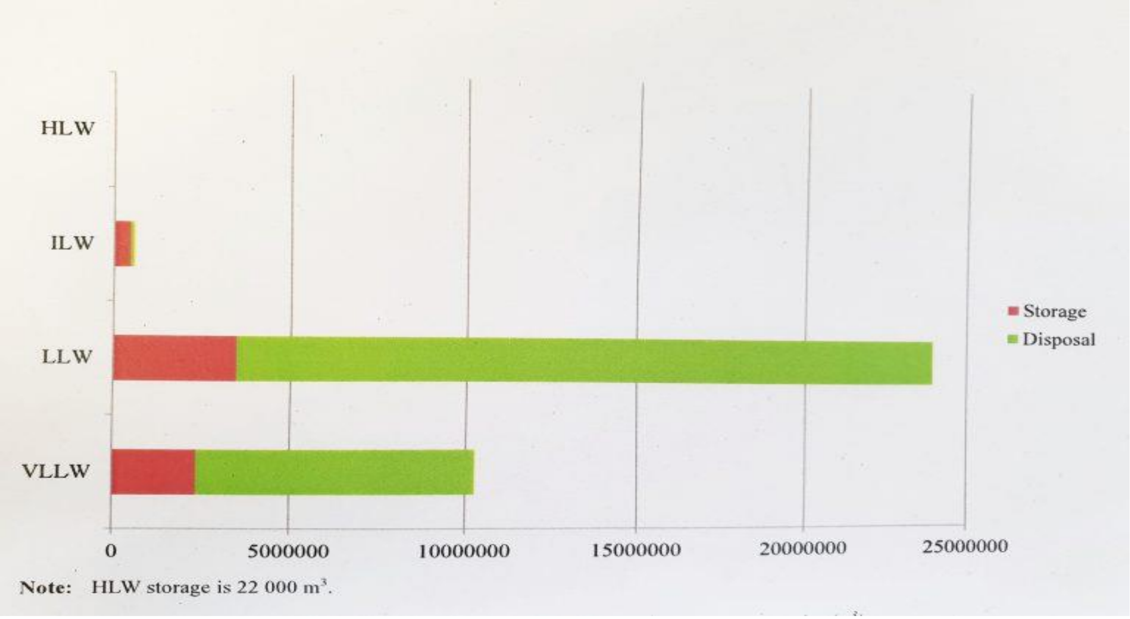
WASTE



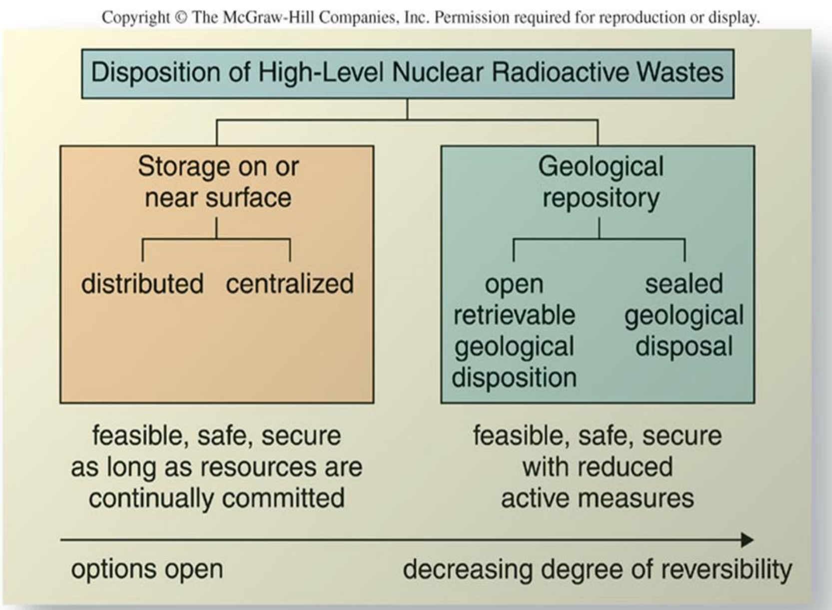
- WILL ONLY TALK ABOUT HWL AND LLW – ESTIMATES VARY HOW MUCH HLW BETWEEN 1% AND 3%
- UK NUCLEAR "DUSTBIN" - A POPULAR REFRAIN
- COST CLEAN UP OF FOSSIL FUELS NOT CONSIDERED – CAN BE ASTRONOMIC

WASTE WORLDWIDE

95% of existing radioactive waste has very low level (VLLW) or low-level (LLW) radioactivity, 4% is intermediate level waste (ILW) 1% is high-level waste (HLW).



HIGH LEVEL WASTE (HLW)



THE GENERATION OF ELECTRICITY FROM A TYPICAL 1 000 MEGAWATT (MWE) NUCLEAR POWER STATION PRODUCES APPROXIMATELY 25–30 TONNES OF SPENT FUEL PER YEAR.

THIS EQUATES TO ONLY THREE CUBIC METRES OF VITRIFIED WASTE IF THE SPENT FUEL IS REPROCESSED;

HLW IS ACCUMULATING AT 12 000 TONNES PER YEAR WORLDWIDE;

THIS VOLUME OF SPENT FUEL, PRODUCED BY ALL OF THE WORLD'S NUCLEAR REACTORS IN A YEAR, WOULD FIT INTO A STRUCTURE THE SIZE OF A SOCCER FIELD AND 1.5 METRES HIGH—EVEN WITHOUT ANY BEING REPROCESSED FOR RE-USED;

BY WAY OF COMPARISON, A 1 000 MWe COAL-FIRED POWER STATION PRODUCES SOME 300 000 TONNES OF ASH ALONE PER YEAR;

THIS CONTRASTS WITH THE 25 BILLION TONNES OF CARBON WASTE RELEASED DIRECTLY INTO THE ATMOSPHERE EACH YEAR FROM THE USE OF FOSSIL FUELS.

HIGH LEVEL WASTE (HLW)

- FIRST STORED UNDER WATER TO ALLOW FOR COOLING;
- CAN BE TRANSFERREED TO DRY STORAGE
- UK LARGELY STORED AT SELLAFIELD
- COST OF DECOMMISSIONING IS OLD NUCLEAR PLANTS ESTIMATED TO BE **£131 BN** IN THE UK
- THE POWER STATIONS THAT NEED DECOMMISSIONING INCLUDE 11 MAGNOX POWER STATIONS BUILT BETWEEN THE 1950S AND 1970S,
- SEVEN ADVANCED GAS-COOLED REACTORS BUILT IN THE 1990S, INCLUDING DUNGENESS B, WHICH CLOSED LAST YEAR, HINKLEY POINT B AND HEYSHAM 1 AND 2 IN LANCASHIRE.

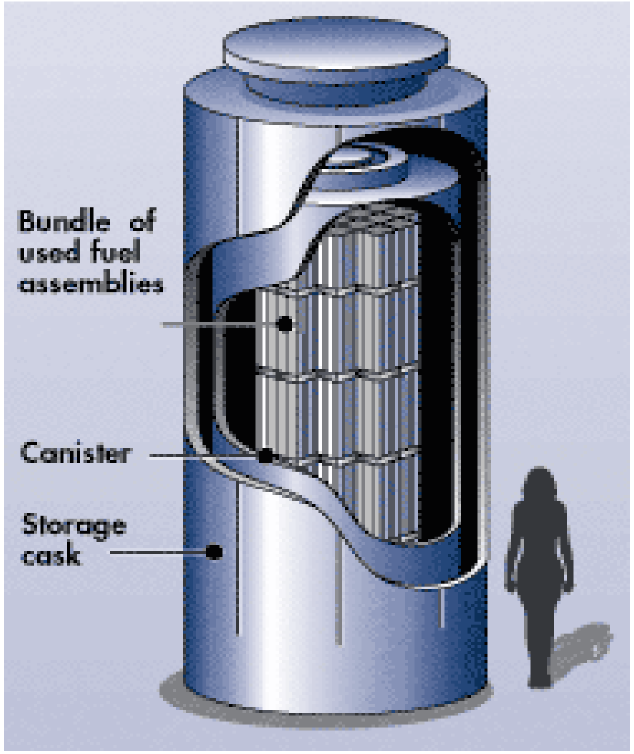
HIGH LEVEL WASTE (HLW)

- ACTIVTE FOR 1,000 – 10,000 YEARS
- ACTIVITY THE SAME AS BEFORE USE
- 1 - 3% IS HLW
- 2/3 STORED, 1/3 REPROCESSED – UK STOPPED REPROCESSING 2020
- DEEP GEOLOGICAL REPOSITORIES (DGRs) - MUST BE GEOLOGICALLY STABLE
- FINLAND IS EXPECTED TO START OPERATING ITS DGR IN THE MID-2020s, - FIRST IN WORLD - ONKALO
- SITE SELECTIONS IN CANADA, FRANCE, SWEDEN AND SWITZERLAND.

SPENT FUEL

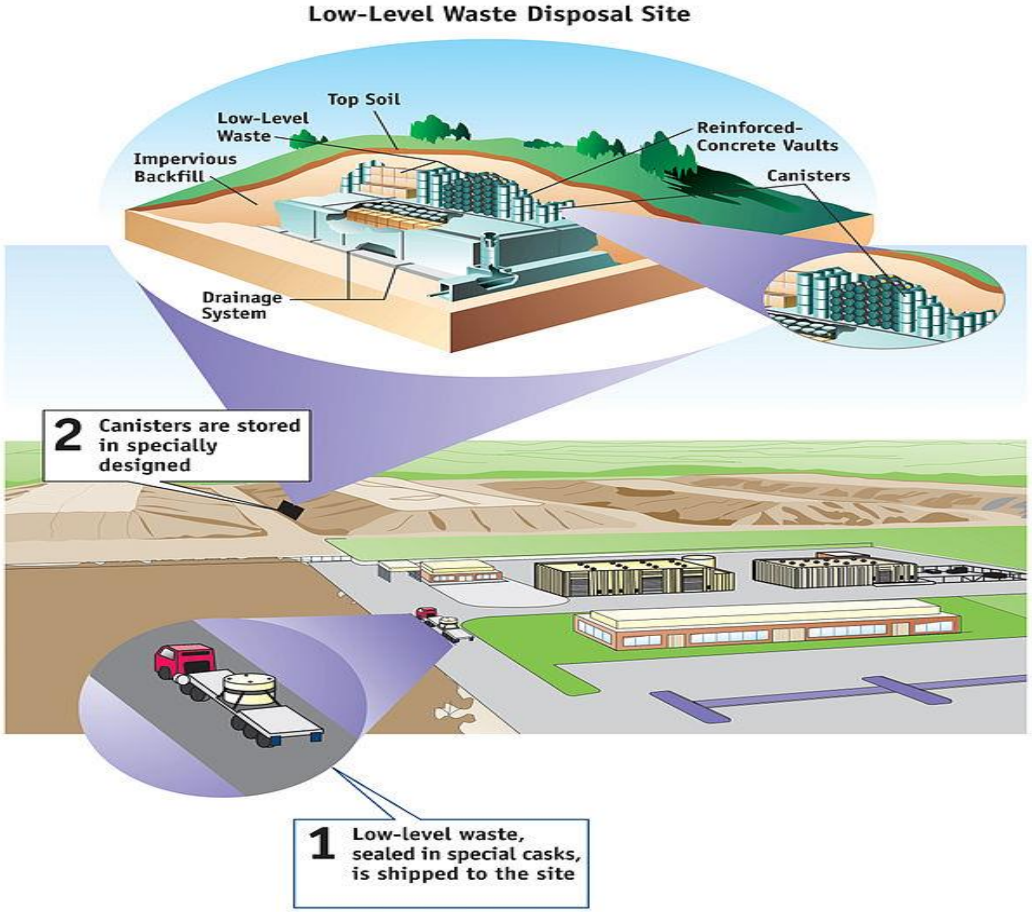
- VITRIFACTION
- CORROSION PROBLEMS REMAIN, HOW DO YOU TEST FOR 1000 YEARS?
- CANISTER – STAINLESS STEEL AND CONCRETE
- MANY NUCLEAR REACTORS NEAR THE COAST
- DANGER OF GROUND WATER INCURSION, AEROSOLS OF NaCl

CANISTER PROTECTION



- SWIMMING POOLS
- STAINLESS STEEL
- CONCRETE
- WET STORAGE – 6 – 10 YEARS
- DRY STORAGE

WASTE: LOW LEVEL



LOW LEVEL WASTE

- IT COMPISES PAPER, RAGS, TOOLS, CLOTHING, FILTERS, ETC., WHICH CONTAIN SMALL AMOUNTS OF MOSTLY SHORT-LIVED RADIOACTIVITY. TO REDUCE ITS VOLUME;
- LLW IS OFTEN COMPACTED OR INCINERATED BEFORE DISPOSAL. LLW COMPRISES SOME 90% OF THE VOLUME BUT ONLY 1% OF THE RADIOACTIVITY OF ALL RADIOACTIVE WASTE;
- UK MAIN FACILITY IN SELLAFIELD.

SUMMARY

WE HAVE SEEN HOW A REACTOR WORKS

THE TYPES OF REACTOR

WASTE

- HLW
- LLW

COSTS

LATEST NEWS

- AT LEAST TWO NEW LARGE-SCALE NUCLEAR PLANTS BY 2030 IN ADDITION TO FIVE SMALL MODULAR REACTORS.