19 AIChE Spring Meeting

15TH GLOBAL CONGRESS ON PROCESS SAFETY

NEW ORLEANS • 2019

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Hilton New Orleans Riverside

THE FUTURE OF POWER AND ENERGY

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> 50 years relevant experience

CLIMATE CHANGE PREVENTION

- leave fossil fuels in the ground
- use Nuclear Power and Renewable Energy

RENEWABLE ENERGY IS INTERMITTENT AND SEASONAL

NUCLEAR POWER PROVIDES DEPENDABLE ELECTRICITY

U-235 IS NOT SUSTAINABLE FOR FOSSIL FUEL DISPLACEMENT

INTERNAL WATER COOLING
> UNSUSTAINABLE WASTE PRODUCTION

WATER COOLING > LOW ELECTRICITY GENERATION EFFICIENCY

HIGH INTERNAL PRESSURE

- Robust pressure containment
- Robust reactor enclosure
- Public Safety Exclusion Zone

REMOTE REACTORS > LITTLE COMMERCIAL USE OF SURPLUS HEAT

MOST EXISTING POWER REACTORS > DO NOT BALANCE RENEWABLE GENERATION

NEW REACTOR FUEL CYCLE > FAST NEUTRON REACTORS

FNR FUEL TUBE ALLOY > NOT RESOLVED UNTIL ABOUT 1990

FNRs > FUEL SUSTAINABLE

100X to 400X reduction in uranium consumption

Dominant Reactions:

2 n + U-238 > n + Pu-239 > 2.91 n + FP + Energy

and

2 n + Th-232 > n + U-233 > 2.48 n + FP + Energy

FNRs > WASTE SUSTAINABLE
1000X Improvement

FNRS > STABLE ELECTRICITY GRID

FNRs are compatible with solar and wind electricity generation

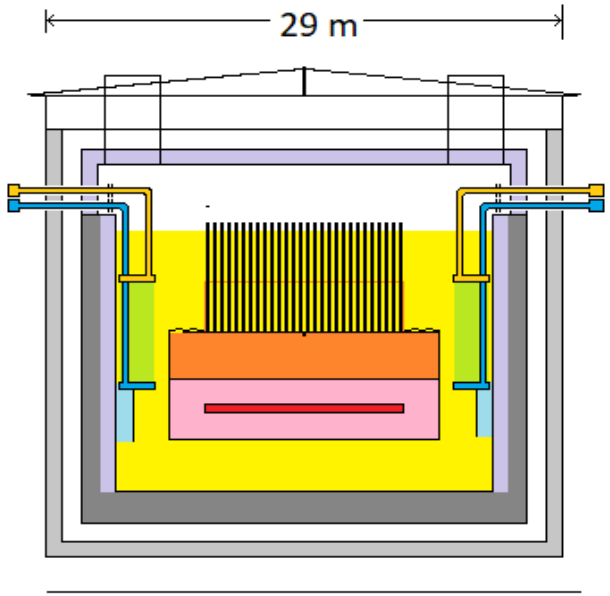
FNRs > ENABLE URBAN REACTOR SITING FOR COMMERCIAL, INDUSTRIAL AND DISTRICT HEATING

FNR DEPLOYMENT

- US abandoned the field in 1994
- Russians are dominant
- Chinese are catching up

FNR SIDE CROSS SECTION

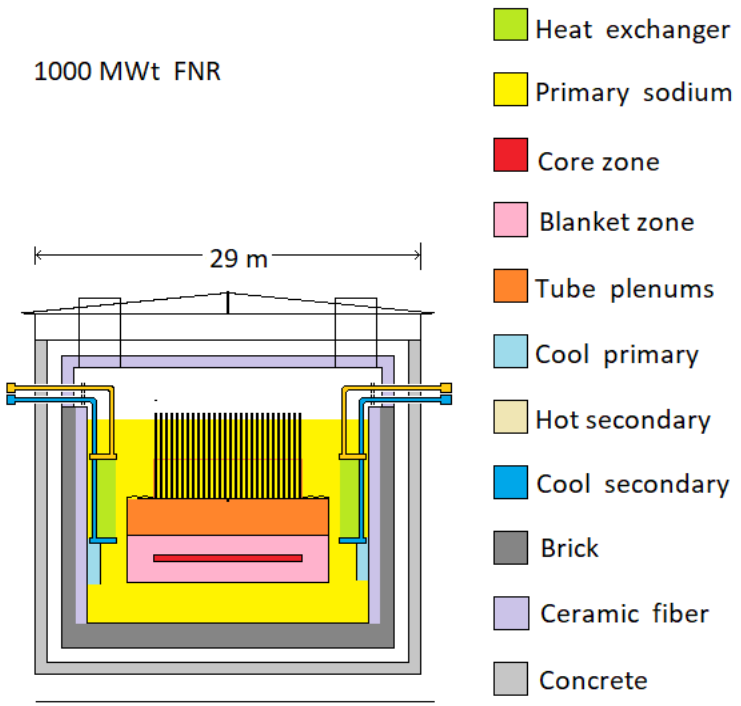
1000 MWt FNR

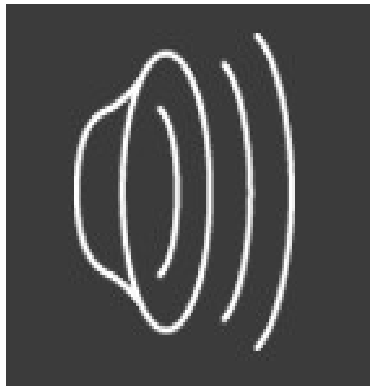


- Heat exchanger
- Primary sodium
- Core zone
- Blanket zone
- Tube plenums
- Cool primary
- Hot secondary
- Cool secondary
- Brick
- Ceramic fiber
- Concrete

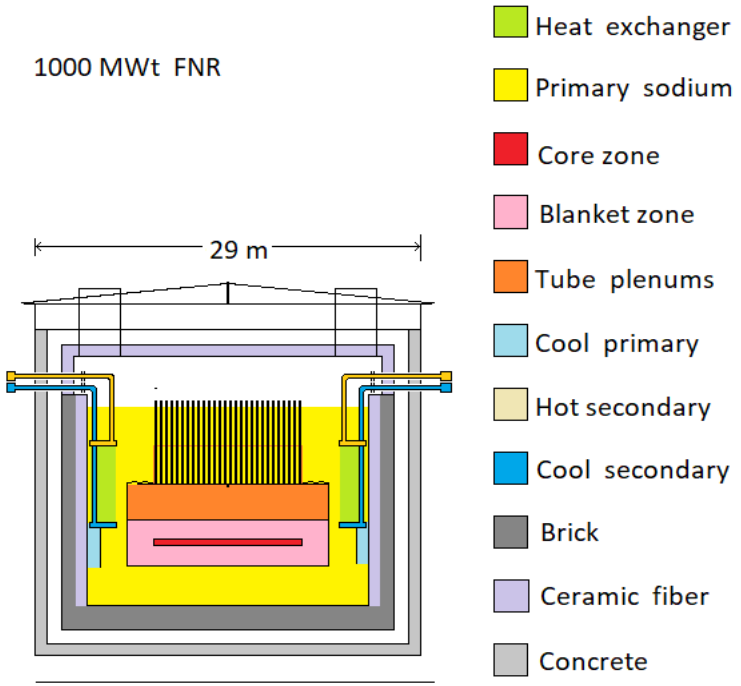
FNR OPERATION

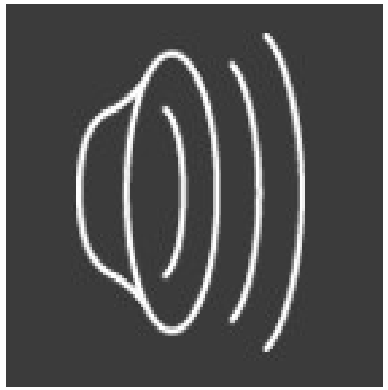
Core (Pu fission neutrons) >Blanket (Pu formation)





FNR GUARD BAND > LONG SODIUM POOL LIFE





FNR OPERATING TEMPERATURE

- Set at 450 deg C by fuel geometry
- regulated by thermal expansion and contraction

FNR SAFETY

- Site above maximum possible flood level
- atmospheric pressure
- air cooling, natural sodium circulation
- loss of control power > cold shutdown

-formation of Pu-240 > prevents proliferation

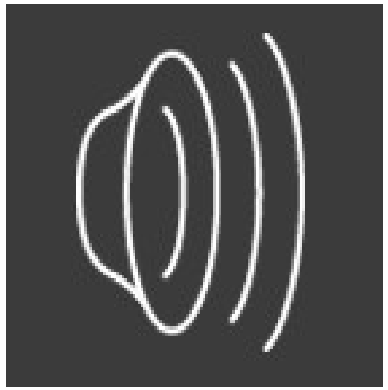
- walk away safe

-autonomous operation

FNR FUEL REPROCESSING

Fuel Source Blanket Core Zr Recovery Storage

U-238 > Pu-239 > FPs > Containers



FISSION PRODUCT DECAY & CHEMICAL SEPARATION

- 300 years in isolated storage
- subsequent chemical separation of radio active elements
- yields stable rare earth elements

REMAINING RADIOACTIVE ELEMENTS
> DEEP GEOLOGIC REPOSITORY
- 1000 fold mass reduction

FNR CORE FUEL =
20% Pu, 70% U-238, 10% Zr

ELECTRICITY MARKET PROBLEMS

Presently when non-fossil generation > load
excess non-fossil power is discarded.

Presently when non-fossil generation < load
fossil fueled generation is used

MATCHING LOAD TO GENERATION

In the future > Non-fossil generation unconstrained

Adjust Total Load to equal Non-fossil generation

Total Load = Uncontrolled Load + Interruptible Load

Interruptible Electricity = New Energy Category

INTERRUPTIBLE ELECTRICITY APPLICATIONS

- charge energy storage
- electrolytic hydrogen production
- heating fuel displacement

NEW ELECTRICITY RATE STRUCTURE

Each consumer has:

- a load requiring Dependable Power
- a load that relies on Interruptible Power

The interruptible load is enabled by the electricity distributor only when the distributor's total Dependable Power load is satisfied.

CAREER OPPORTUNITIES

a) High purity sodium 5000 tonnes / 1000 MWt

b) Ferrochrome tubing 2600 km / 1000 MWt)

c) Selective uranium oxide extraction

d) Reduction of spent fuel oxides to metals

CAREER OPPORTUNITIES CONTINUED

e) High temperature electrolytic separation of low and high atomic weight elements;

f) Selective zirconium extraction;

g) Productioon of porcelain-metal containers;

h) Production of synthetic liquid fuels from hydrogen, biomass and nuclear reactor heat.

TAKE AWAY MESSAGES:

a) Renewable energy is intermittent and seasonal, Dependable Power is from hydro and FNRs;

b) FNRs Feature:

- improved safety
- 100X better fuel efficiency
- 1000X less long lived waste
- load following

c) Conserve: spent reactor fuel, Pu-239, U-235

TAKE AWAY MESSAGES CONTINUED

d) Interruptible Electricity rate enables use of otherwise discarded non-fossil electricity

e) Chemical Engineering Opportunities In:

- Fast Neutron Reactors and fuel reprocessing
- hydrogen and synthetic fuels
- energy storage systems