

A CANDU-TYPE SMALL/MEDIUM POWER REACTOR

by

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THE CANDU SMR STORY

✘ “If you want a smaller fire, just use fewer logs”

-- John Foster, former president of AECL

✘ In the beginning, there was NPD

✘ Back to the future?

+ Now, we need a small power reactor for remote sites

+ NPD produced 22 Mwe (gross) - about the right size

+ Site needs and modern knowledge -- to be added

THE SMALL MEDIUM-OR-MODULAR REACTOR

- ✘ Small may be beautiful, but big is cheap
 - + Given the same project criteria, this is always true
 - + Changing the rules can make the statement false
- ✘ Niche market or strange financing conditions
 - + Small demand – remote, off-grid location
 - + Aberrant rules for charging costs into the rate base
- ✘ Large units carry obsolescent reference designs
 - + Too big for the market?
 - + Too many frills – a touch of Byzantium?

DYNAMICS OF REACTOR DEVELOPMENT

- ✘ Some difficult project objectives
 - + Ideal – a brand new design with an operating record
 - + Ideal – solves old operating problems but opens no new licensing questions
 - + Ideal – it is accepted as safe by a majority of people
 - + Ideal – privately owned, but government funded
 - + Ideal – much cheaper than those that came before

A PRACTICAL CASE – CDN. REMOTE POWER CORP

- ✘ Reliable, economic, energy needed for projects communities, bases at remote Northern sites.
 - + Fuel oil is expensive
 - + Grid connections are non-existent
- ✘ Company is interested in 25 Mwe units
 - + Delivery schedule “as soon as possible”
- ✘ NPD ran successfully for 25 years
 - + The “all Canadian” solution

REACTOR DESIGN OPTIONS

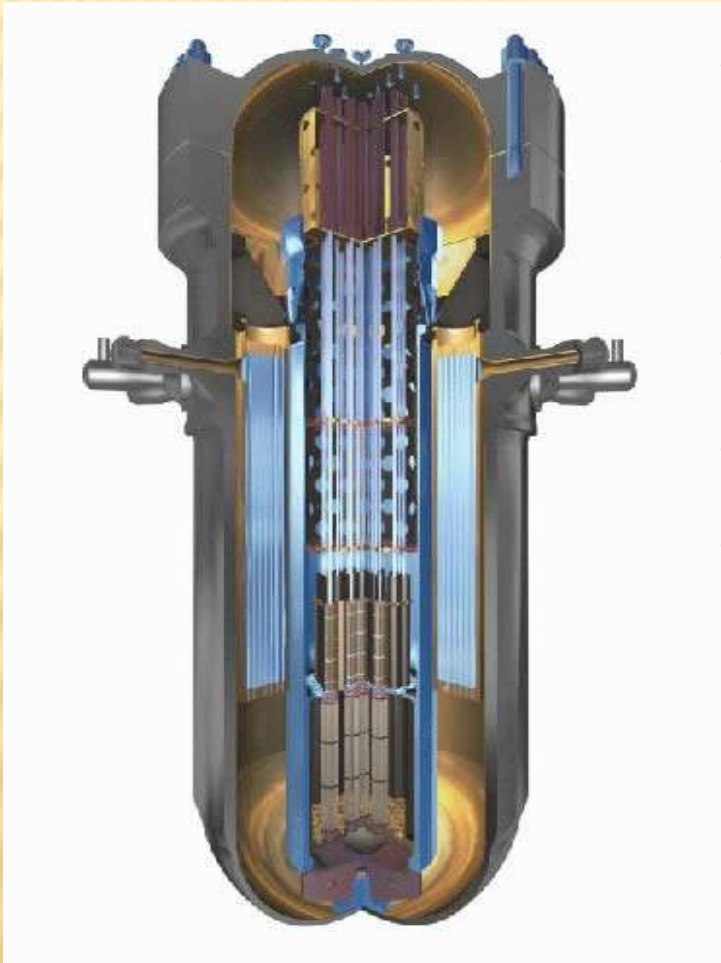
CANADA REMOTE POWER CORPORATION

- ✘ Argentina – CAREM
- ✘ The all-Canadian option - CANDU
- ✘ Sub Critical Assembly (SCA)

- ✘ Candidates eliminated:
 - + Toshiba 4S
 - + Hyperion
 - + Babcock & Wilcox
 - + Russian ABV-6M

- General Atomics TRIGA
- NuScale
- IRIS

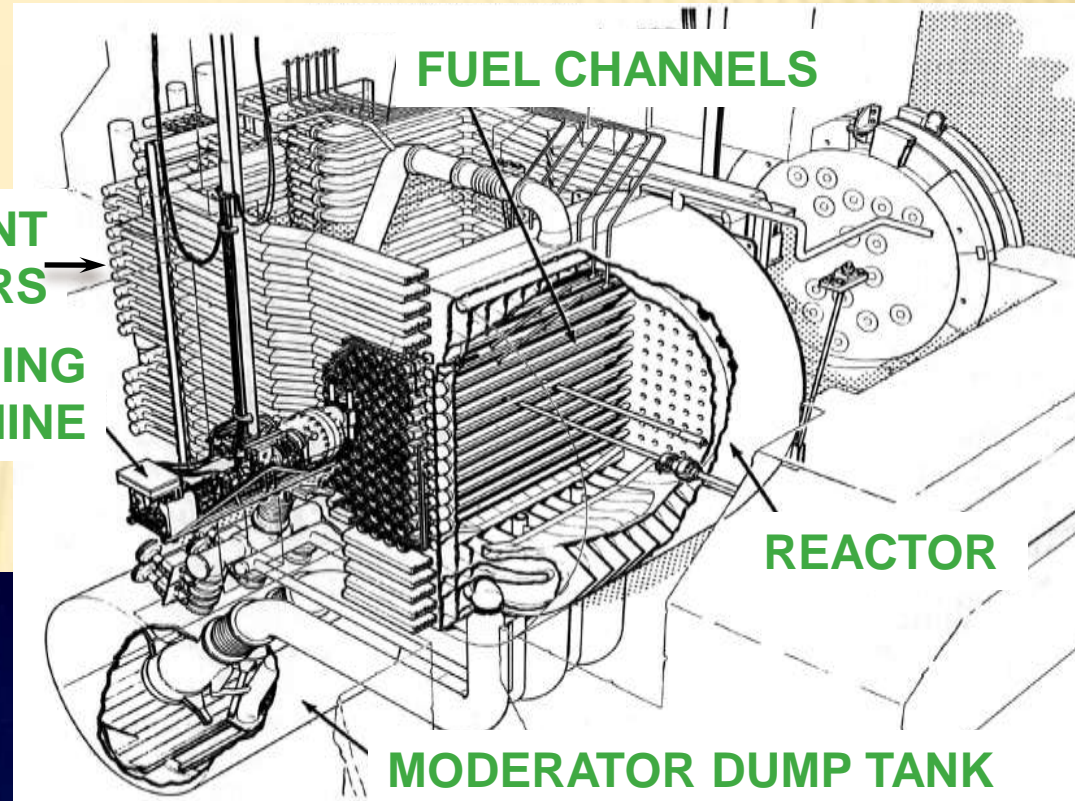
CAREM – ARGENTINA



- 27 MWe integral PWR – IRIS Type
- Compact, relatively portable
- Natural circulation in primary circuit
- Prototype already committed (FOAK)
- Could be operational in 2016
- Weaknesses:
 - licensing process unfamiliar to CNSC
 - lack of power maneuvering capability
 - pressure vessel is large
 - capital cost estimate is high

A SUCCESSFUL FIRST TRY - NPD-2

COOLANT
FEEDERS
FUELLING
MACHINE



TRY IT AGAIN?

NOT A BIG DEAL



CANADIAN REMOTE POWER CORP - SUMMARY

- Favorable Economics – a good business case
- Canadian Expertise – global recognition
- Remote power is needed in Canada
- Favorable regulatory climate
- Imperative of carbon emissions reduction
- Market not limited to remote sites, once proven
- Useful as a starting point for future designs
- Project suspended – site economics have changed

THE CANDU 80 CONCEPT – HART, 1996

- ✘ 100 Mwe
- ✘ True SMR concept – for remote sites, oil sands
- ✘ Applicable for countries new to nuclear energy
- ✘ Low power density, large operating margins
- ✘ Proven technology throughout
- ✘ Low specific capital cost, low operating cost
- ✘ Short project cycle

CANDU SMR - 50 MW OPTION

- ✘ Made in Canada
- ✘ CNSC Personnel understand the technology
- ✘ 25 years of successful operation of NPD-2
- ✘ Expected “nth” capital cost – About \$150 M
 - + \approx \$3000 - 4000 per kWe
- ✘ Marginal Economics for “nth” installation in Canada

CANDU-SMR CONCEPT & MAJOR FEATURES

- ✘ Basic design principles
 - + Evolution of reference design begins from an earlier concept design – CANDU 80*
 - + Primary objective is electricity and process heat production
- ✘ Major operational features
 - + On-power refueling
 - + Remote fueling from fresh to used fuel bay
 - + Energy storage capability for load levelling
- ✘ Operating concept
 - + Day to day (limited) intervention by local trained staff
 - + Monitoring and visits by expert staff (annual?)

* R.S. Hart, “CANDU 80 Technical Outline”, AECL, (Feb. 1996)

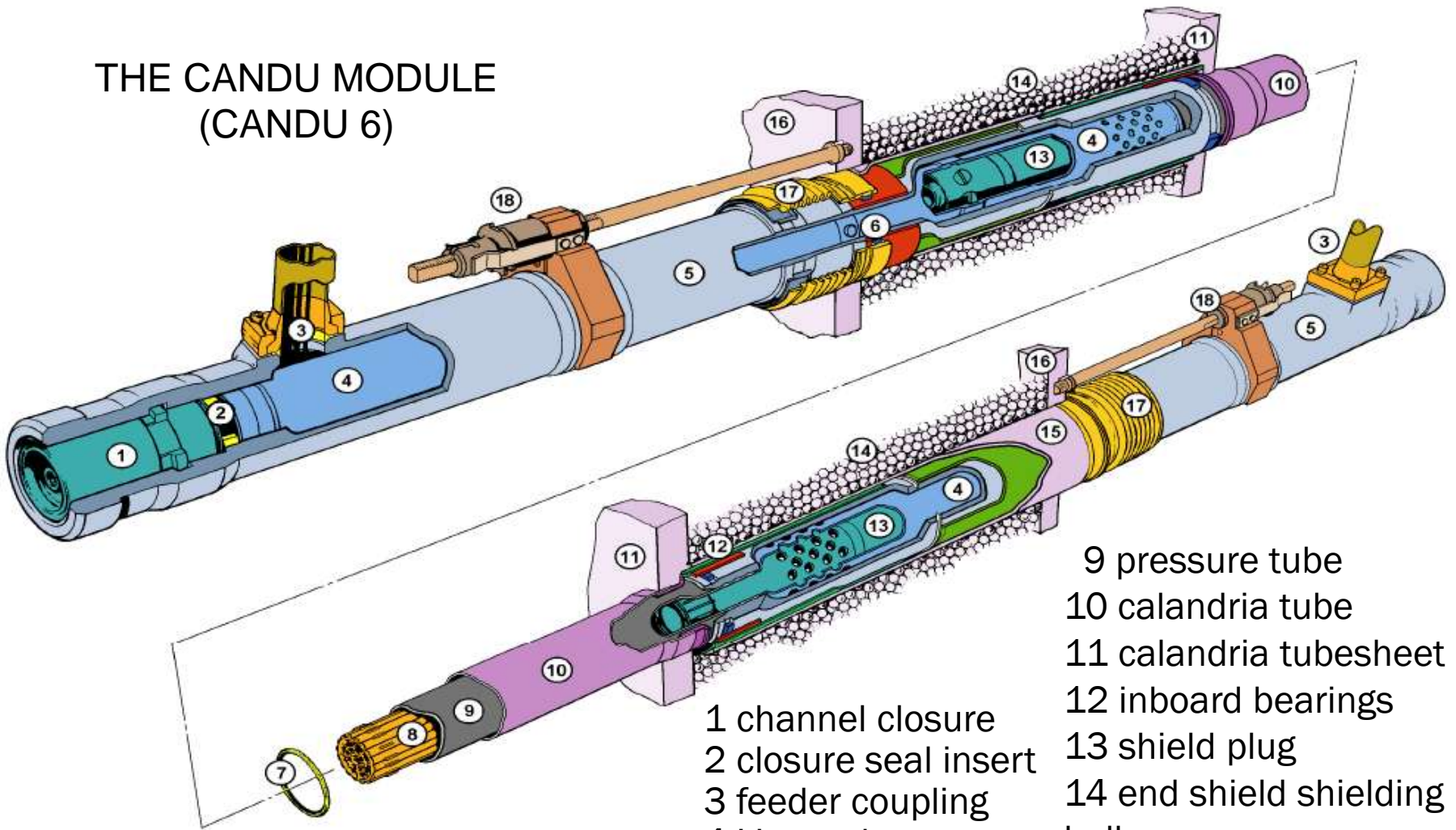
MAJOR SYSTEM PERFORMANCE SPECS

- ✘ Cost-competitive with petroleum for heating and electricity
- ✘ Licensable in Canada, under small-reactor licensing guidelines
- ✘ 100% availability (including backup)
- ✘ “No-freeze” systems via underground placement
- ✘ Portable in segments, both new and as a used facility
- ✘ Full range load following –seconds to days, with energy storage
- ✘ Computer controlled operation plus remote safety intervention
- ✘ Daily fuel changing at power
- ✘ Infrequent fuel restocking – minimum one-year at full power

FUEL SUPPLY

- ✘ Small, inexpensive LEU fuel assemblies
 - + Easily transported, both as new and when used
 - + Useless for unauthorized diversion
- ✘ **Automated fuel movement**
- ✘ Use Gentilly-1 type of fuel system – fuel strings
 - + Automate fuelling from fresh store to used fuel bay
 - + On-site staff only to monitor operation
 - ✘ Annual visit by expert staff to replenish fuel string supply and remove used fuel bundles

THE CANDU MODULE (CANDU 6)



- 1 channel closure
- 2 closure seal insert
- 3 feeder coupling
- 4 Liner tube
- 5 End fitting body
- 6 outboard bearings
- 7 annulus spacer
- 8 fuel bundle

- 9 pressure tube
- 10 calandria tube
- 11 calandria tubesheet
- 12 inboard bearings
- 13 shield plug
- 14 end shield shielding balls
- 15 end shield lattice tube
- 16 fuelling tubesheet
- 17 channel annulus bellows
- 18 positioning assembly

TWO PLANT CONFIGURATIONS

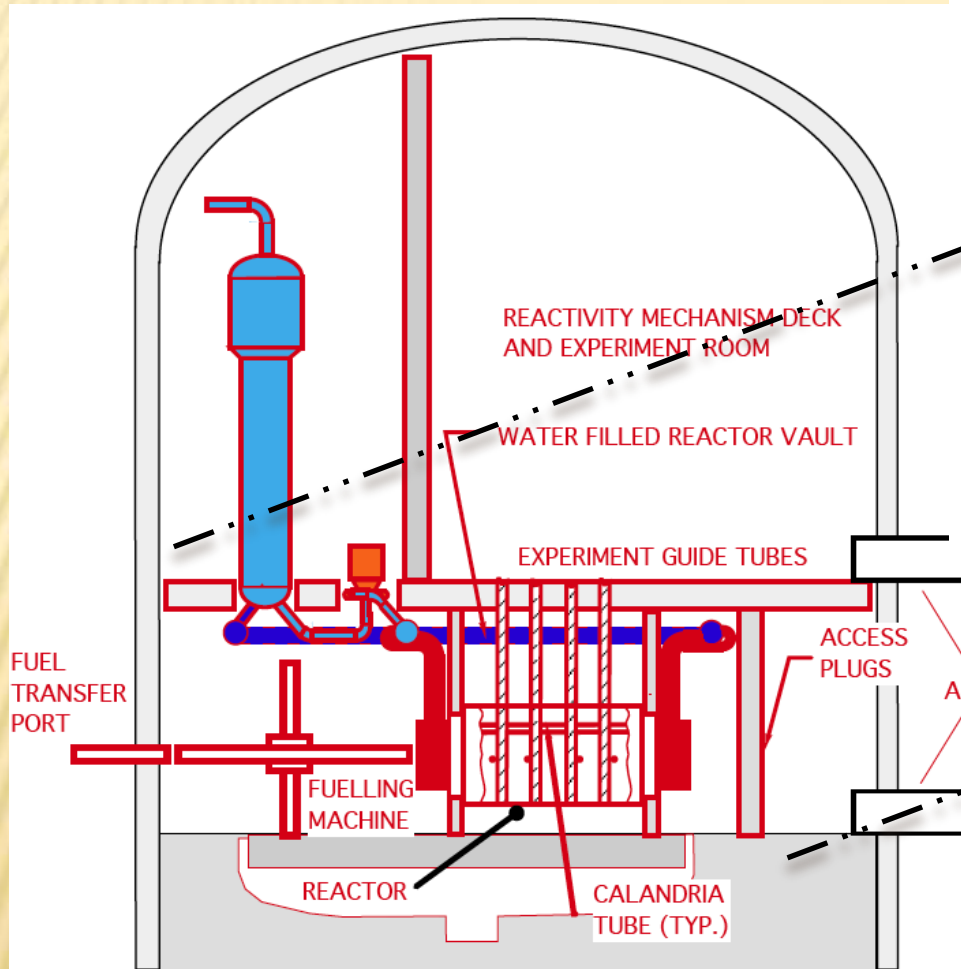


Figure 2(a) – The CANDU ETR

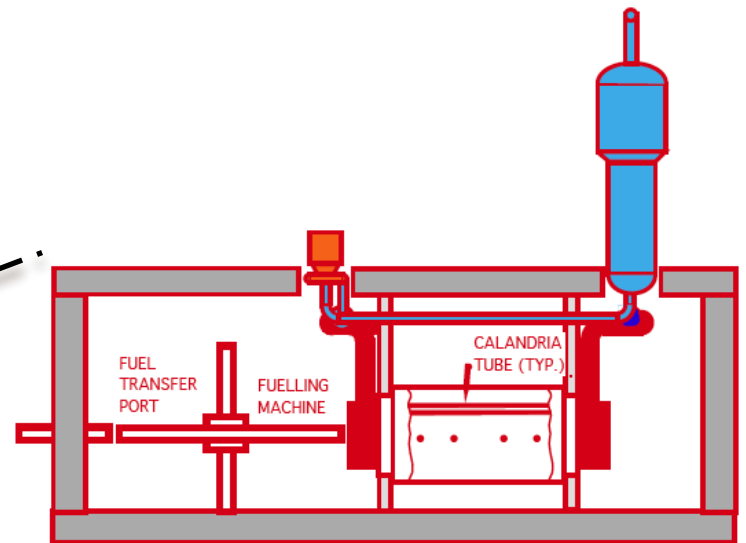
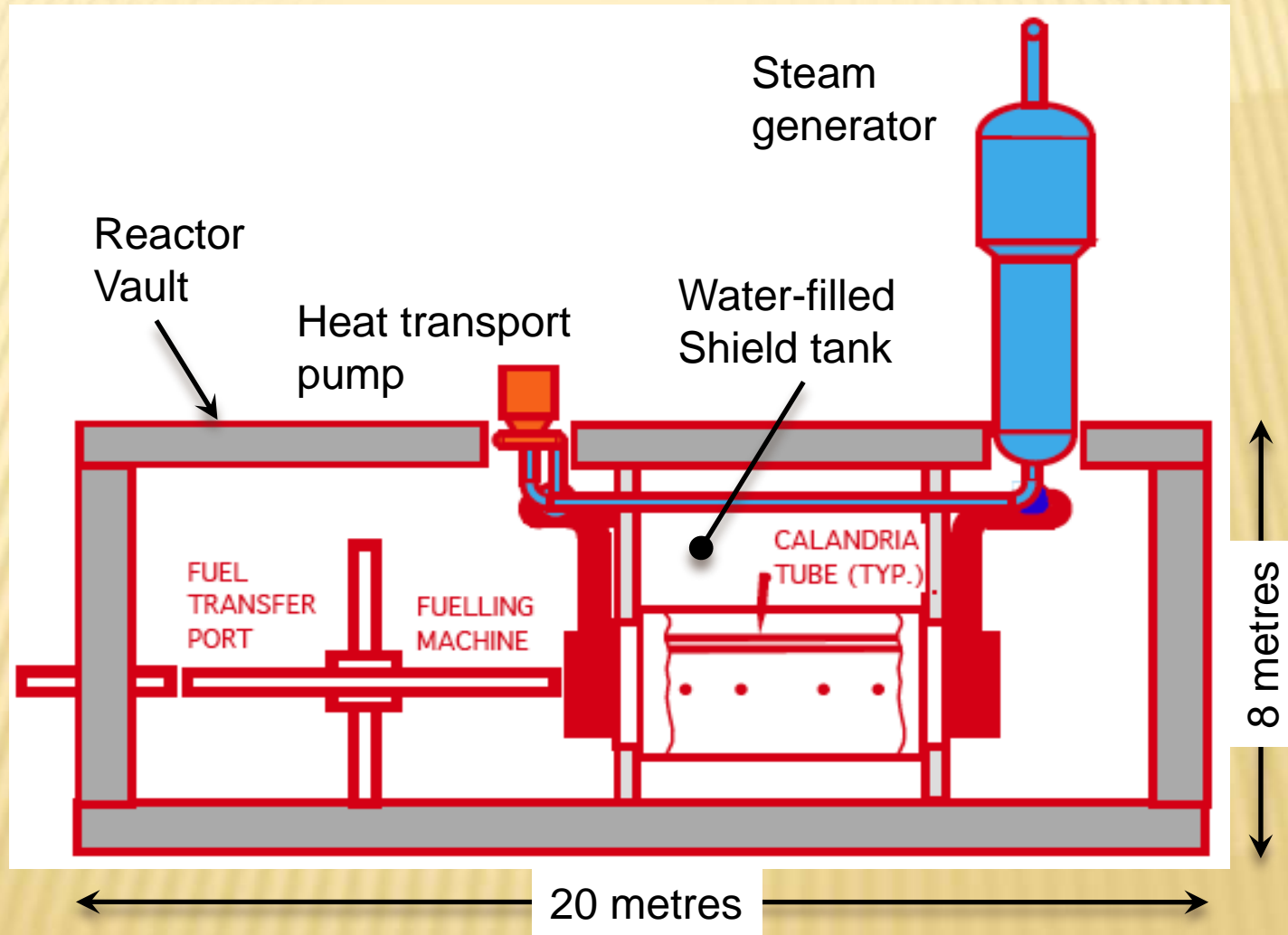
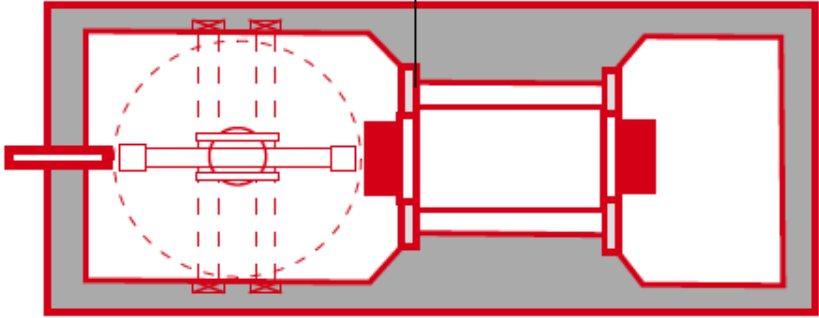
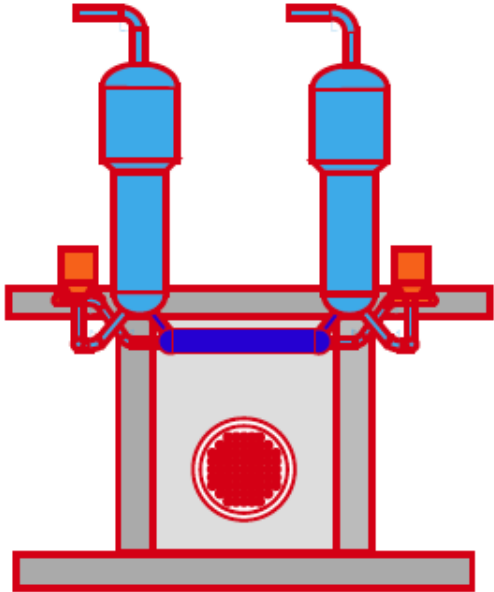
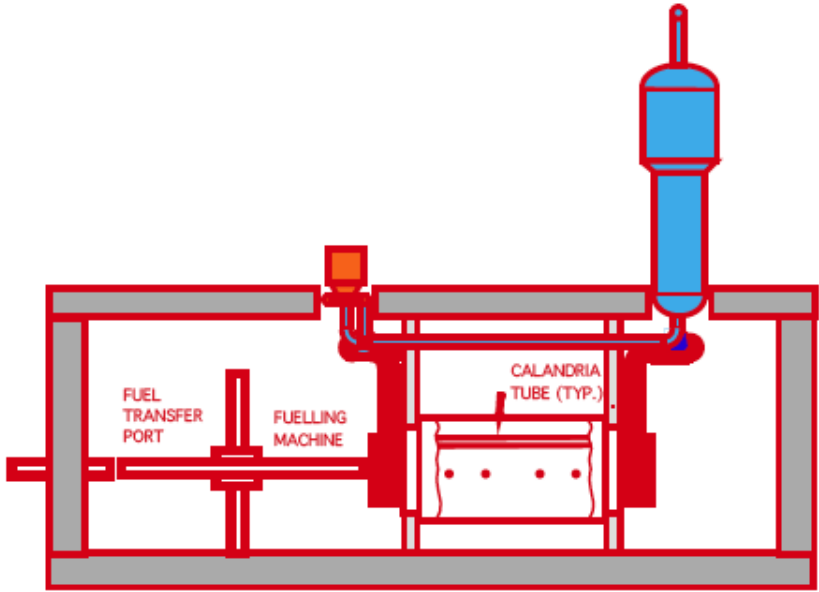


Figure 2(b) – The CANDU SMR

CANDU - SMR CONCEPT



PRELIMINARY SKETCHES – CANDU SMR



DESIGN DECISIONS TO MAKE

Operating policies/principles

Staffing

Licensing

Energy storage

Turbine/generator

Steam generators

Fresh fuel handling

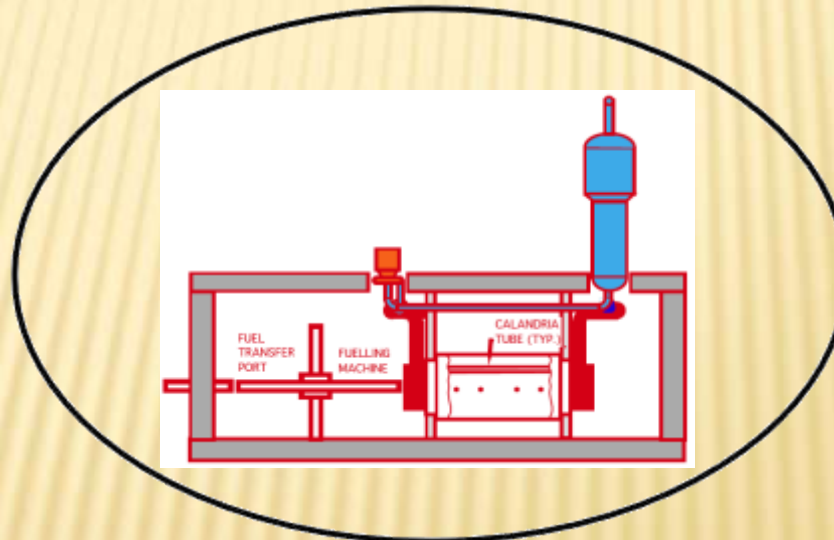
S/G feed water

Used fuel handling

Site grade elevation

Containment

Control systems



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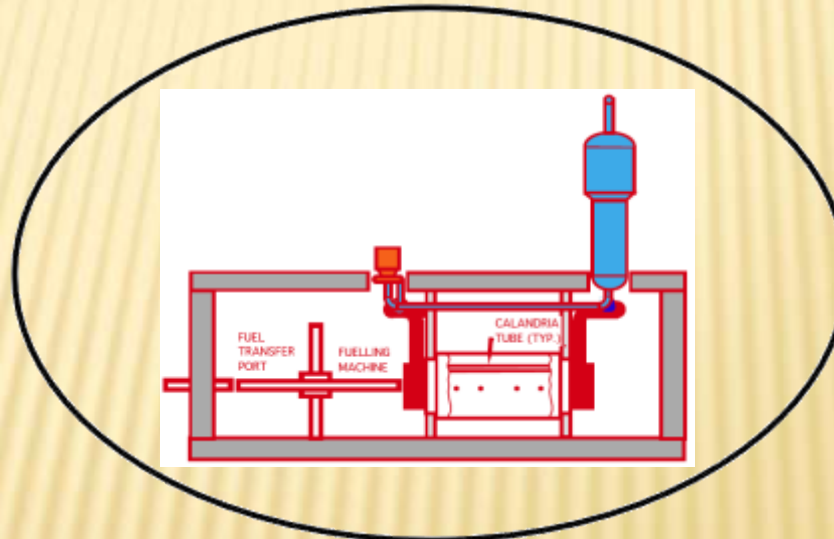
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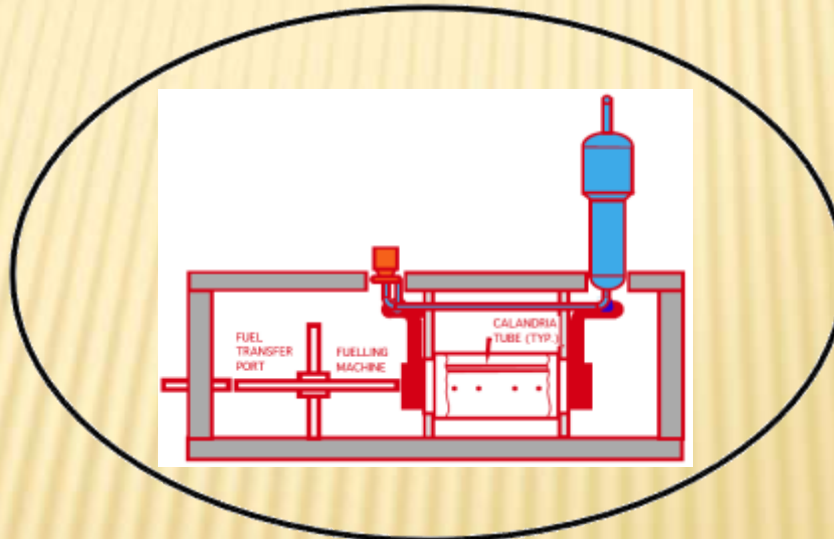
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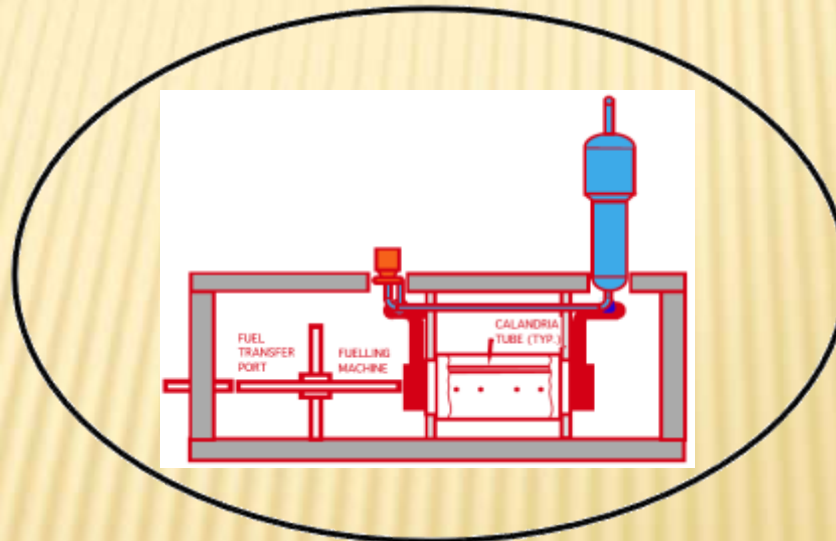
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ENERGY STORAGE

- ✘ Desirable due to highly variable load profile
- ✘ Site loads include large thermal requirement
- ✘ Molten salt tank – heated by excess electricity
 - + Possibly using on-site wind and/or diesel-electric
- ✘ Water tank – excess thermal output of SMR
 - + Possibly using back-pressure turbine

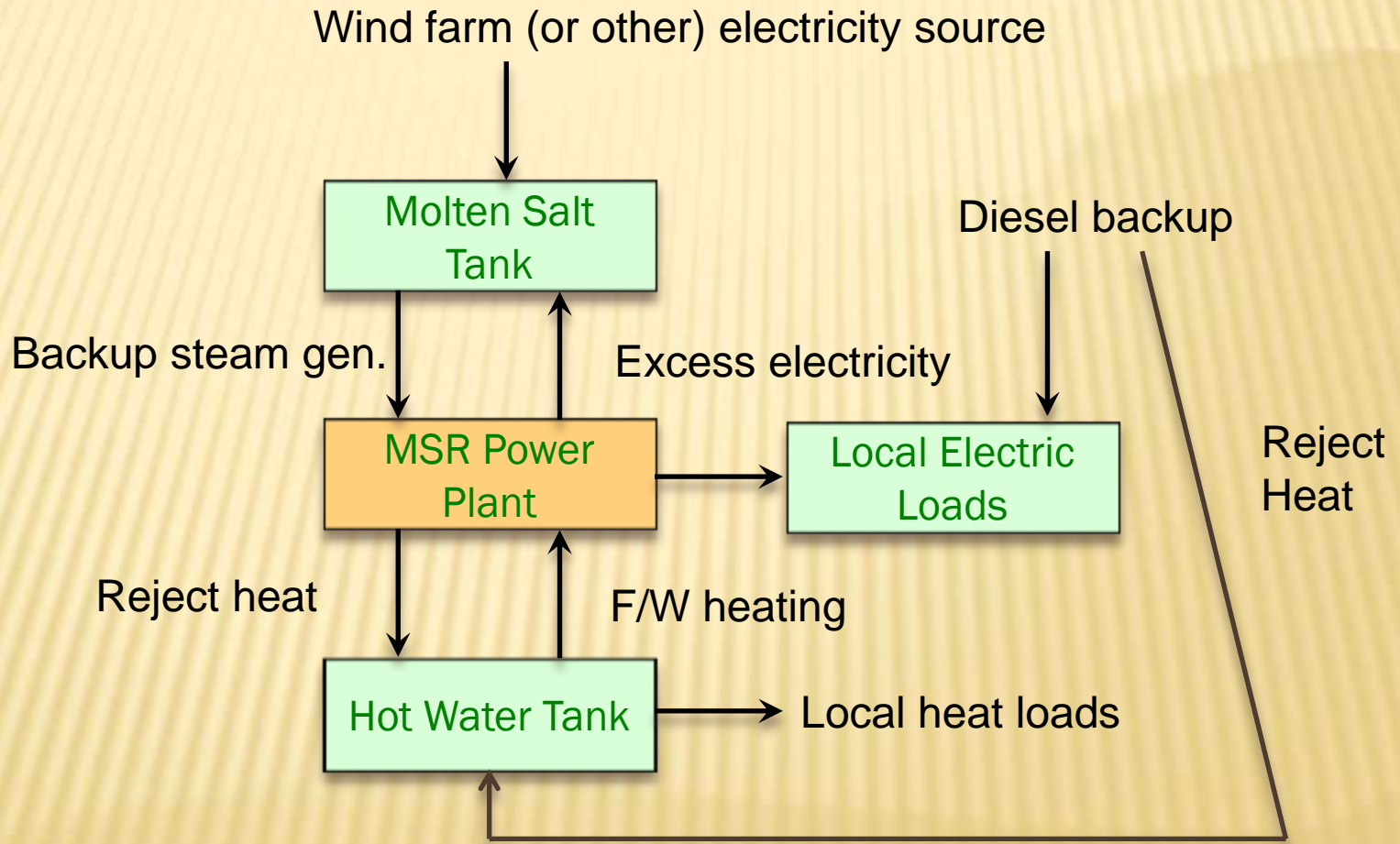
SYNTHETIC OIL PRODUCTION

- ✘ See Charles Forsberg – “Nuclear Beyond Base-load Electricity: Variable Electricity and Liquid Fuels”

<http://canes.mit.edu/sites/default/files/pdf/NES-115.pdf>

- ✘ Consider the balance between small reactors for local service or larger units with regional distribution of liquid fuels

ON-SITE TANK STORAGE CONCEPTS



CANDU SMALL/MEDIUM POWER REACTOR

× Next steps

- + Get the cost down – simplify & refine the concept
- + Confirm the two-step fuelling frequency
- + Minimize operator intervention tasks at local level
- + Find at least one customer
- + Initiate communication/discussion with CNSC
- + Conduct preliminary and detailed design
- + Build/maintain a computer-based design package
- + Refine the cost estimate

SUMMARY

- ✘ Energy supply in the High Arctic is a challenge
 - + Social acceptance is a major factor
 - + There are additional technical challenges
 - + Commercial competition will be fierce
 - + First-of-a-kind risks may be large
 - + Licensing is a big question – as always