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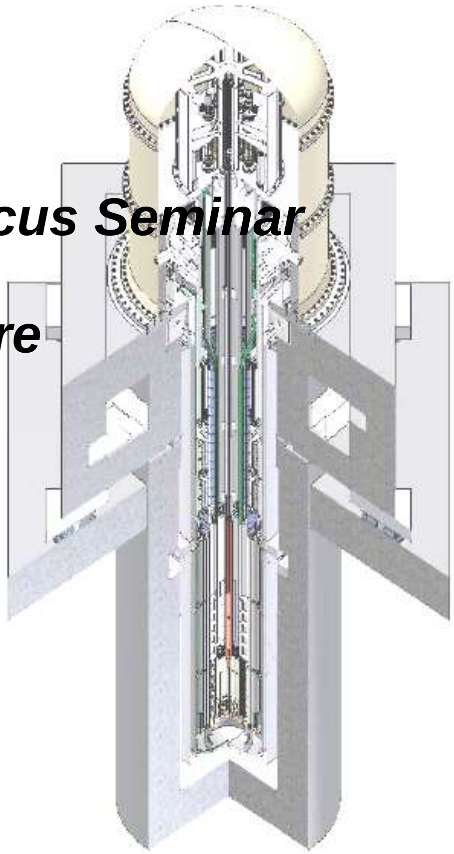
# Applicability of Small Fast Reactor "4S" for Oil Sands Recovery



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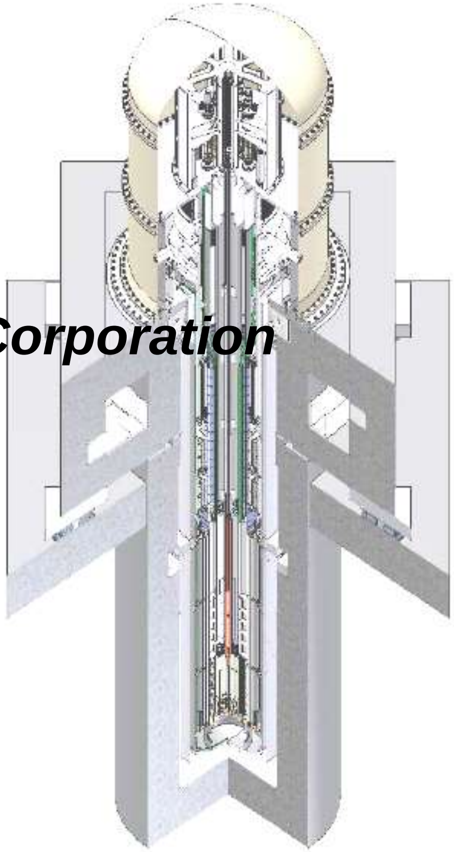
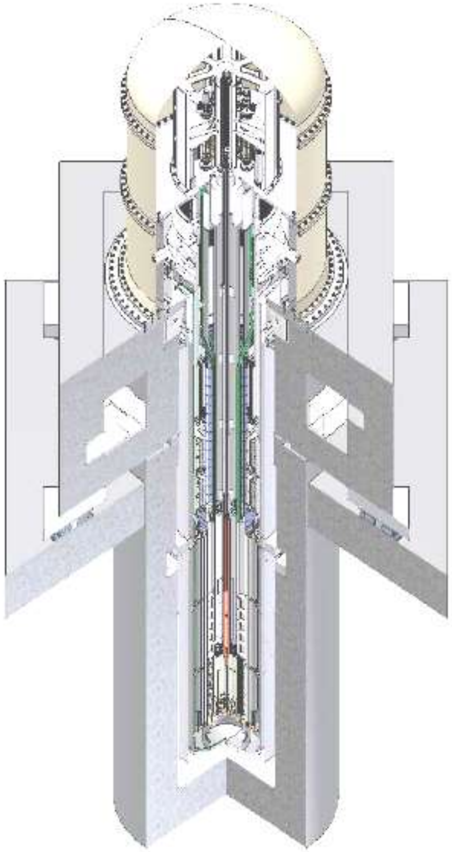
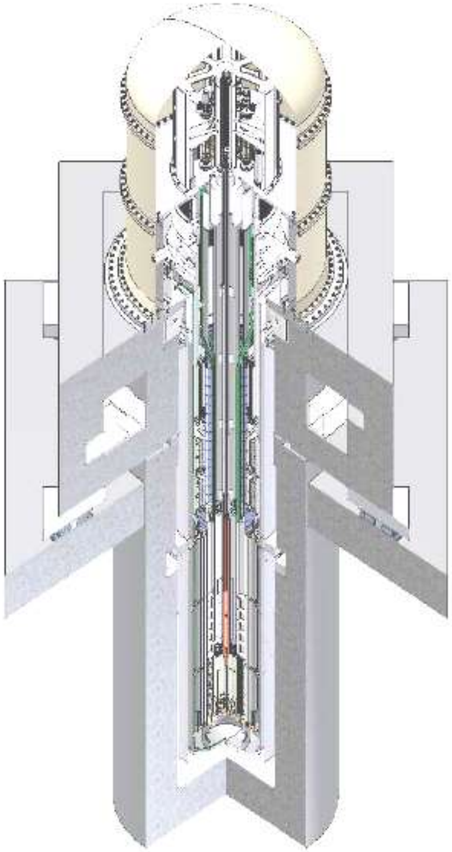


# Outline

1. Overview
2. Design Description
3. Advantages
4. Concluding Remarks

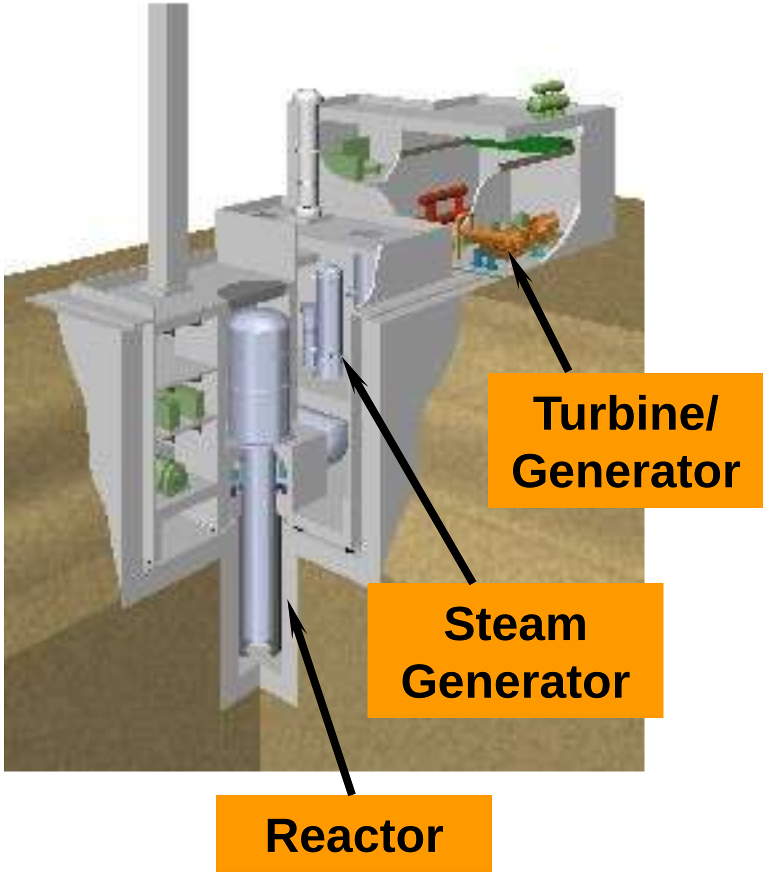


1. **Overview**
   - **Features**
   - **History**
   - **4S Versions and Applications**
2. Design Description
3. Advantages
4. Concluding Remarks



# Features

- **Sodium cooled pool type fast reactor**
- **Versions**
  - **30 MWt (10MWe)**
  - **135 MWt (50MWe)**
- **Main features**
  - **Passive safety**
  - **No onsite refueling or long interval**
    - **30 MWt: 30 years**
    - **135 MWt: 10 years**
  - **Low maintenance requirements for static equipment**
  - **Security enhanced by below grade siting**

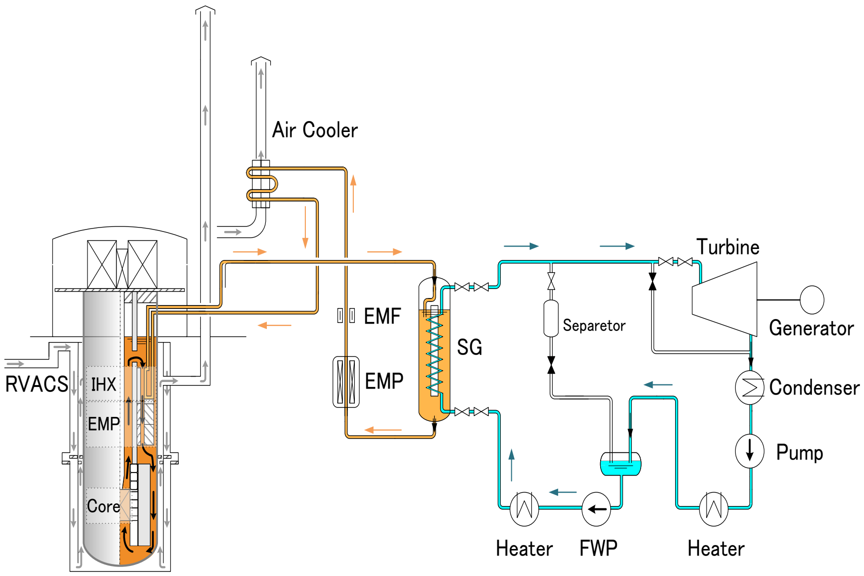


# History

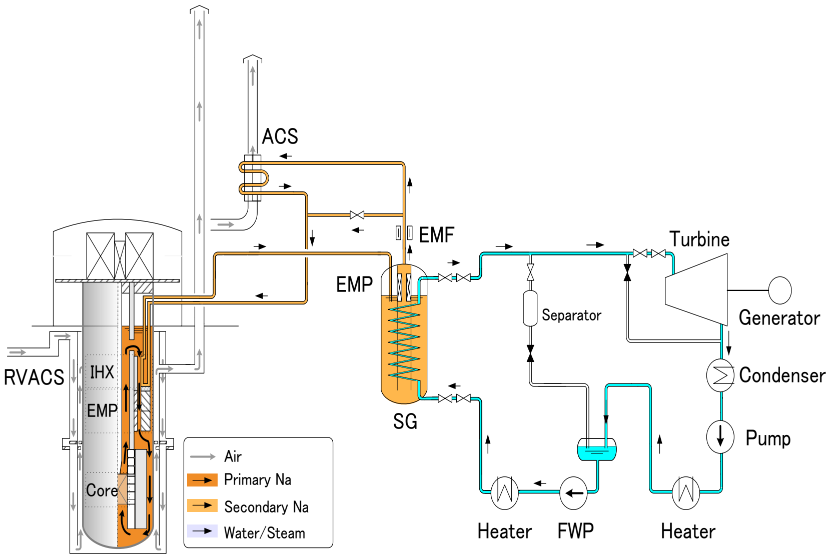
- 1988: Began conceptual design study in Toshiba
- 1991: IAEA seawater desalination study with CRIEPI
- 1993: US DOE's interest
- 2002 - 06: Innovative technology development funded by MEXT
- 2003: Galena, Alaska's interest
- 2004: US DOE's environmental assessment for Galena matter
- 2006: White paper for 4S introduction issued by Galena
- 2006: Selected one of the candidate reactors in GNEP SMR Working Group (collaboration between DOE – METI)
- 2007: Began study for application to oil sands treatment
- 2007: Began the pre-review of US NRC on 10MWe-4S
- 2008: Began key components demonstration funded by METI

# 4S Versions and Applications

## Electric supply versions




**10MWe / 30 MWt**
**Non-refueling (30 years)**




**50MWe / 135 MWt**
**Refueling Interval: 10years**

**In this study, "4S-135MWt" is applied to supply steam instead of electricity for bitumen recovery from oil sands assuming Steam Assisted Gravity Drainage (SAGD) method.**

# Application for Canadian Oil Sands

| In Situ Projects | Bitumen Production [b/d] | Required Power for Steam Supply [MWt] | In Situ Projects | Bitumen Production [b/d] | Required Power for Steam Supply [MWt] |
|---|---|---|---|---|---|
| Chevron Canada Ellis River | 100,000 | 767 | KNOC BlackGold | 20,000 | 153 |
| CNRL Birch Mountain | 30,000 | 230 | Laricina Germain | 1,800 | 14 |
| CNRL Gregoire Lake | 30,000 | 230 | MEG Christina Lake | 23,880 | 183 |
| CNRL Kirby | 30,000 | 230 | NAOSC (Statoil) Kai Kos Dehseh | 140,000 | 1073 |
| CNRL Leismer | 15,000 | 115 | Nexen Long Lake | 72,000 | 552 |
| CNRL Primrose/Wolf Lake | 120,000 | 920 | Nexen Long Lake South | 70,000 | 537 |
| Connacher Great Divide | 10,000 | 77 | North Peace Energy Red Earth | 1,000 | 8 |
| ConocoPhillips Surmont | 25,000 | 192 | Patch Ells River | 10,000 | 77 |
| Devon Jackfish | 35,000 | 268 | Petrobank (Whitesands) | 90,000 | 690 |
| EnCana Borealis | 32,500 | 249 | Petro-Canada Chard | 40,000 | 307 |
| EnCana Christina Lake | 30,000 | 230 | Petro-Canada Meadow Creek | 40,000 | 307 |
| EnCana Foster Creek | 30,000 | 230 | Petro-Canada Lewis | 40,000 | 307 |
| Enerplus Kirby | 25,000 | 192 | Petro-Canada MacKay River | 40,000 | 307 |
| Husky Caribou Lake | 10,000 | 77 | Shell (BlackRock) Orion (Hilda Lake) | 10,000 | 77 |
| Husky Sunrise | 50,000 | 383 | Shell Peace River | 50,000 | 383 |
| Husky Tucker | 30,000 | 230 | Suncor Firebag | 68,000 | 521 |
| Imperial Oil Cold Lake | 30,000 | 230 | Total (Deer Creek) Joslyn | 15,000 | 115 |
| JACOS Hangingstone | 25,000 | 192 | Value Creation Terre de Grace | 40,000 | 307 |

Source: Strategy West Inc. Report (2008)

Assumption: 230 MWt for 30,000 b/d

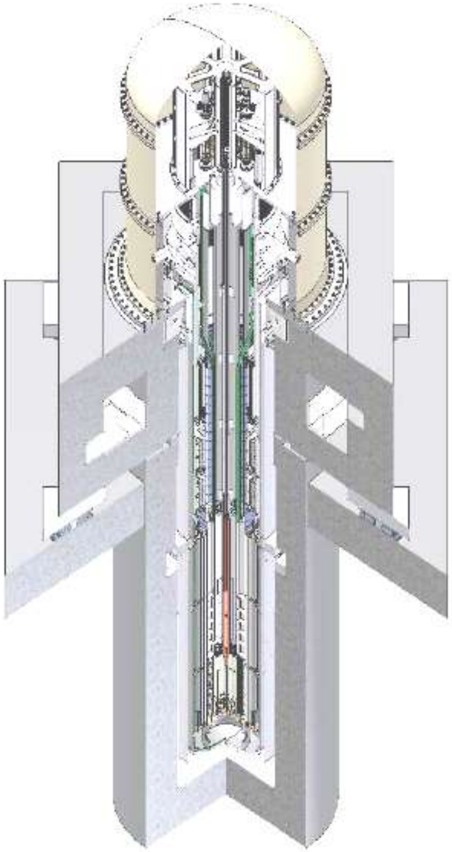
***Many sites require small power system (red columns)***

1. Overview

2. **Design Description**
   - Reactor System
   - Heat Transport System
   - Reactor Building

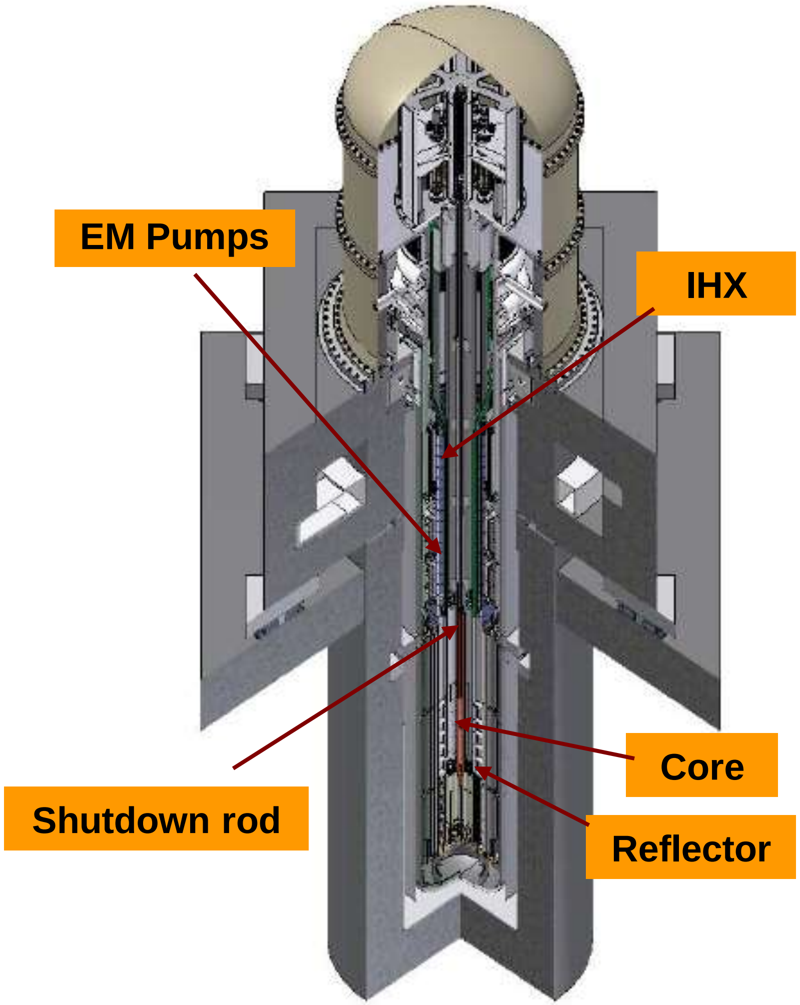
3. Advantages

4. Concluding Remarks



# Reactor System

- Metallic fuel core (U-10%Zr)
- Reactivity control by movable reflectors
- Shutdown system by reflectors and a shutdown rod
- Passive shutdown by metallic fuel properties during ATWS
- Electromagnetic pumps have no moving parts

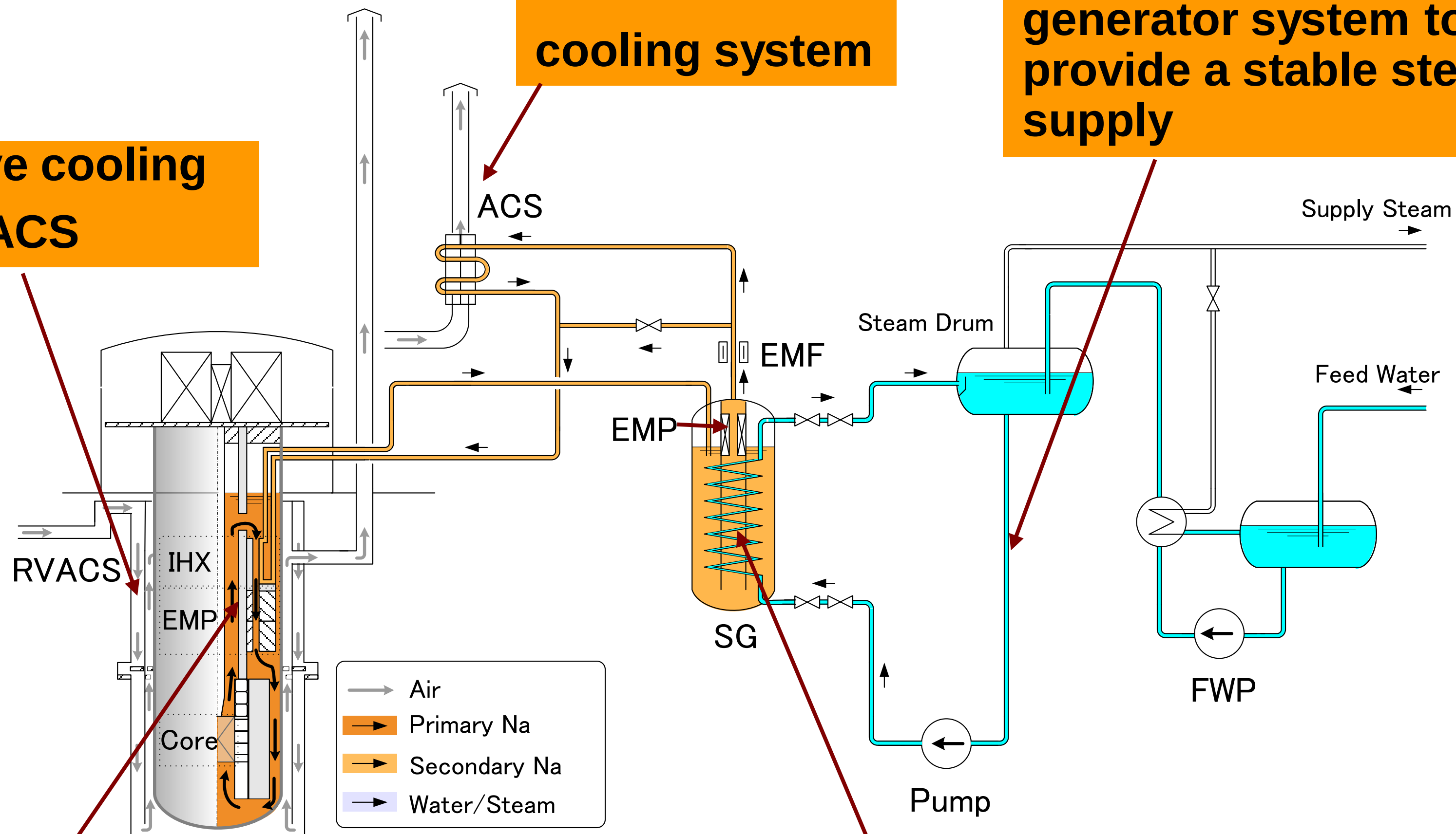


# Heat Transport System

**IRACS cooling system**

**Recirculating-type steam generator system to provide a stable steam supply**

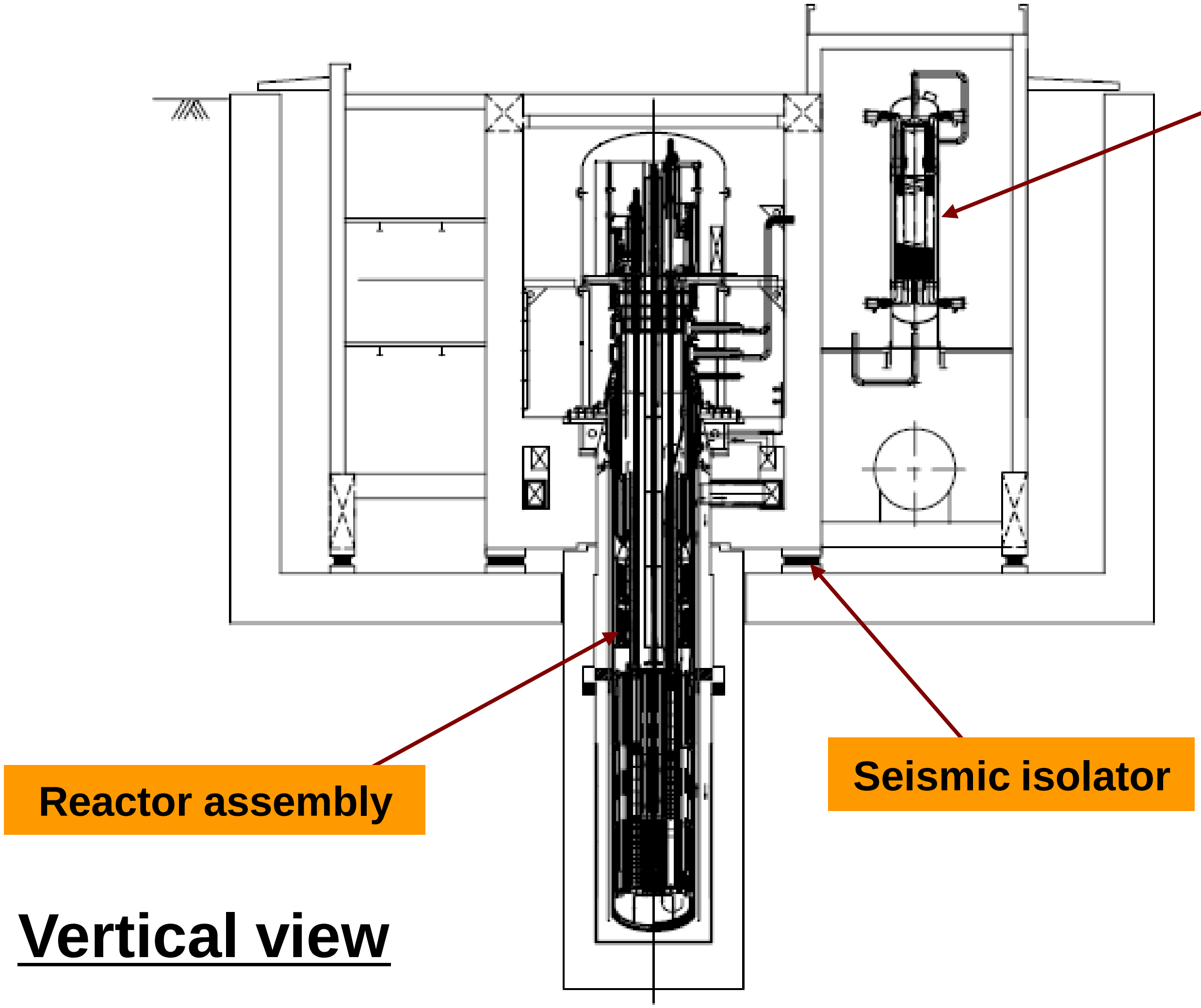
**Passive cooling by RVACS**

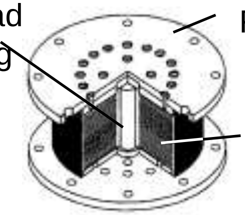



**Integrated assembly of IHX and EM pumps**

**Helical-coil type double-wall steam generator**

# Reactor Building




**Horizontal seismic isolator**

**Vertical view**

# Design Parameters

| | |
|---|---|
| Type | Sodium cooled pool type fast neutron reactor |
| Thermal Output | 135 MWt |
| Number of Loops | 1 |
| Plant / Fuel Life Time | 30 / 10 years |
| Fuel / Clad Material | U-10%Zr / HT-9 |
| Sodium Core Inlet / Outlet Temperature | 355 / 510 degrees C |
| Steam Supply Condition to SAGD plant | 310 degrees C, 10.0 MPa |
| Steam Supply Flow Rate to SAGD plant | 238 t/h |
| Decay Heat Removal System | RVACS + IRACS |
| Reactivity Control System | Reflector Controlled |
| Primary EM Pump | Linear annular induction type |
| Intermediate Heat Exchanger (IHX) | Vertical shell-and-tube type straight tube |
| Steam Generator | Double wall tube with wire mesh,<br>helical coil type |
| Reactor Vessel Dimensions | Inner diameter : 3.6 m<br>Total height : 25 m |
| Reactor Building Dimensions | 31 m Long, 25 m Wide, 22 m High |

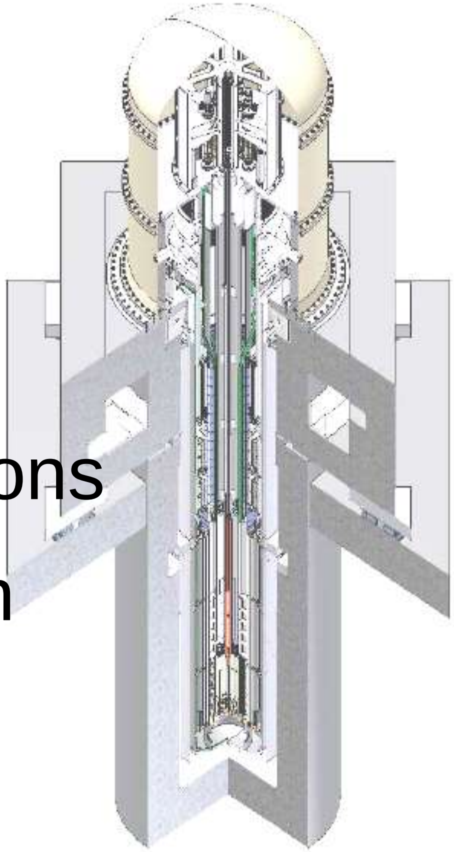
1. Overview

2. Design Description

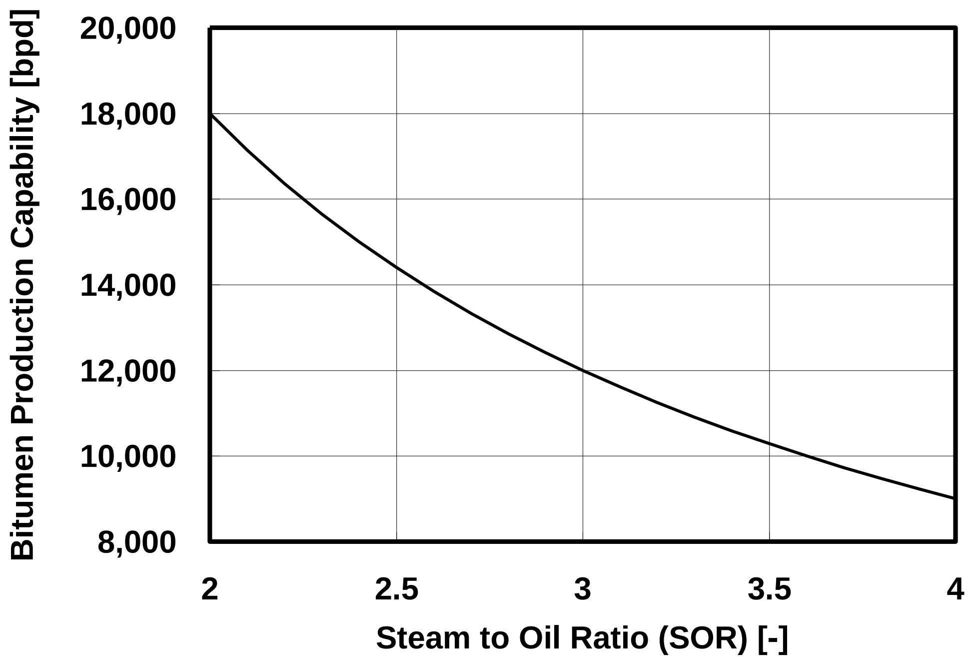
## 3. Advantages

- Bitumen Production
- Plant Availability
- Greenhouse Gas (GHG) Emissions
- Modular Concept & Construction

4. Concluding Remarks



# Bitumen Production




- ✓ **One unit of 4S-135 MWt supplies steam for a relatively small SAGD plant to produce approx. 12,000 bpd of bitumen (@ SOR=3)**
- ✓ **The modular concept of 4S is a fit for oil sands application.**

**4S-135 MWt Capability**

# Plant Availability

- ✓ **Core life time is 10 years**
- ✓ **Low maintenance requirements**
- ✓ **Outage for refueling and maintenance : less than 1 month**

↓

**Plant availability**

**10 years / (10 years + 1 month) = 99%**

# Greenhouse Gas (GHG)

**One unit of 4S-135 MWt plant supplies approx. 2 x $10^6$ t/y of steam to a SAGD plant corresponding to 9000 – 18,000 bpd production of bitumen.**

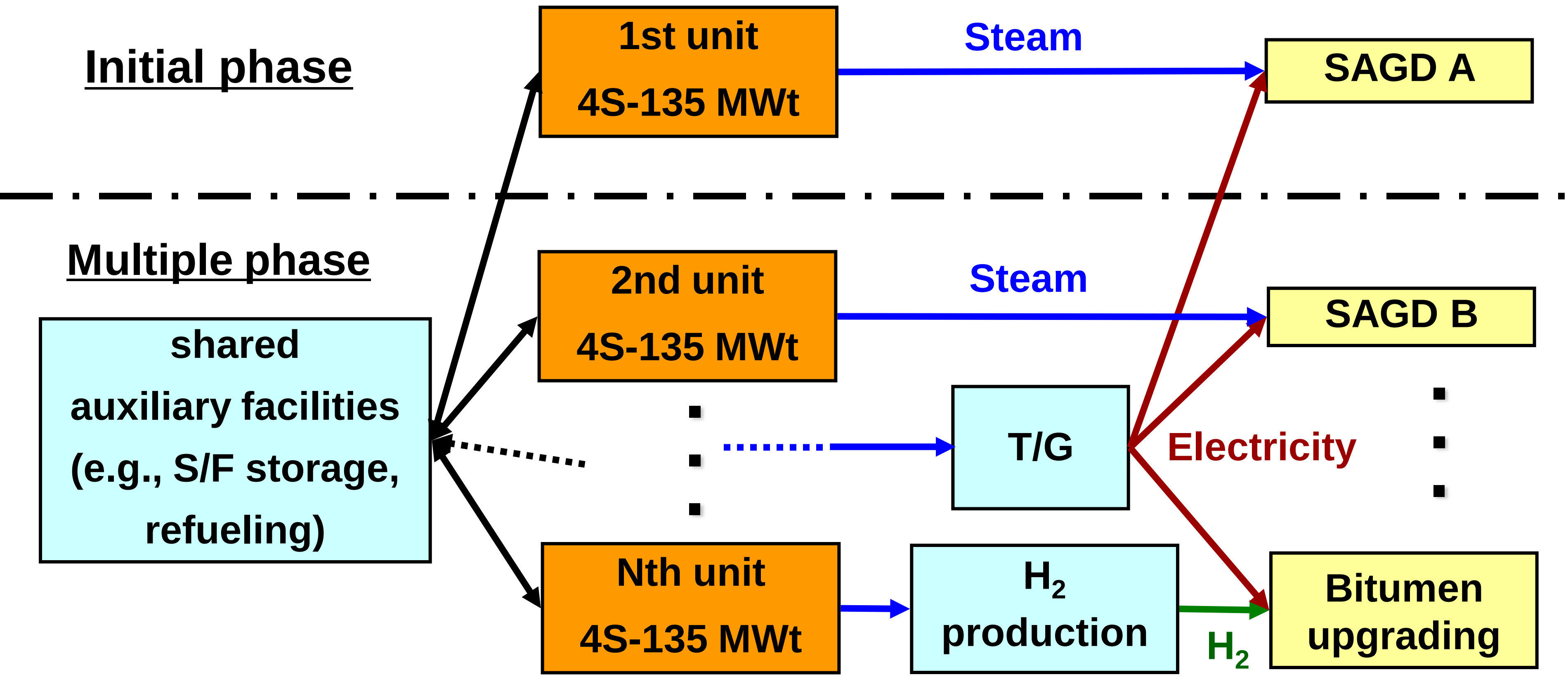
***Reduces approx. 400,000 t of $CO_2$ emissions per year (compared with a natural gas plant )***

**Further,**

**4S can produce hydrogen more efficiently than conventional nuclear reactors since coolant temperature is high.**

**If 4S is applied to supply hydrogen for upgrading bitumen, GHG emissions can be reduced further.**

# Modular Concept




- ✓ **Low initial costs & risk**
- ✓ **Cost reduction by plant standardization and shared facilities at multiple phase**

# Modular Construction

- ✓ Plant construction of 4S does not heavily depend on:
  - site location
  - site weather conditions
- ✓ Because,
  - the heaviest component is less than 100 tons
  - all components can be delivered to site by truck
  - construction  time is less than 2 years

***4S is a fit for oil sands applications***

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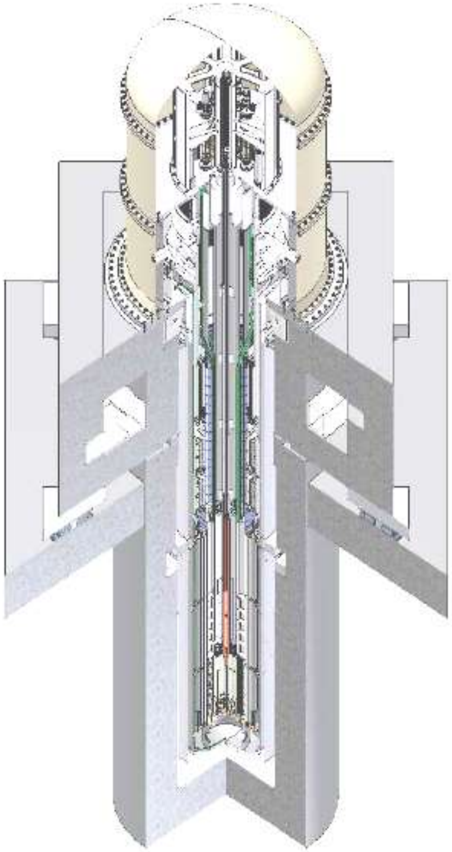

# Concluding Remarks

- ✓ A 4S-135 MWt plant concept supplying steam for a SAGD plant has been developed.
- ✓ The 4S application to oil sands recovery significantly reduces GHG emissions and has numerous advantages.
- ✓ The burden for development and licensing will be reduced in tie-ups with the program for 4S-30 MWt which is now in process of pre-application review by U.S. NRC.

# Acronyms

| | |
|---|---|
| ATWS | : Anticipated Transient without Scram |
| CRIEPI | : Central Research Institute of Electric Power Industry |
| DWSG | : Double-Wall Steam Generator |
| EM pump | : Electromagnetic pump |
| GNEP | : Global Nuclear Energy Partnership |
| GHG | : Greenhouse gas |
| IAEA | : International Atomic Energy Agency |
| IHTS | : Intermediate Heat Transport System |
| IHX | : Intermediate Heat Exchanger |
| IRACS | : Intermediate Reactor Auxiliary Cooling System |
| METI | : Ministry of Economy, Trade and Industry |
| MEXT | : Ministry of Education, Culture, Sports, Science and Technology |
| RVACS | : Reactor Vessel Auxiliary Cooling System |
| SAGD | : Steam Assisted Gravity Drainage |
| SMR | : Small and Medium Reactor |
| SOR | : Steam to Oil Ratio |
| US DOE | : United States Department of Energy |
| US NRC | : United States Nuclear Regulatory Commission |

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