Modular Helium Reactor (MHR) for Oil Sands Extraction

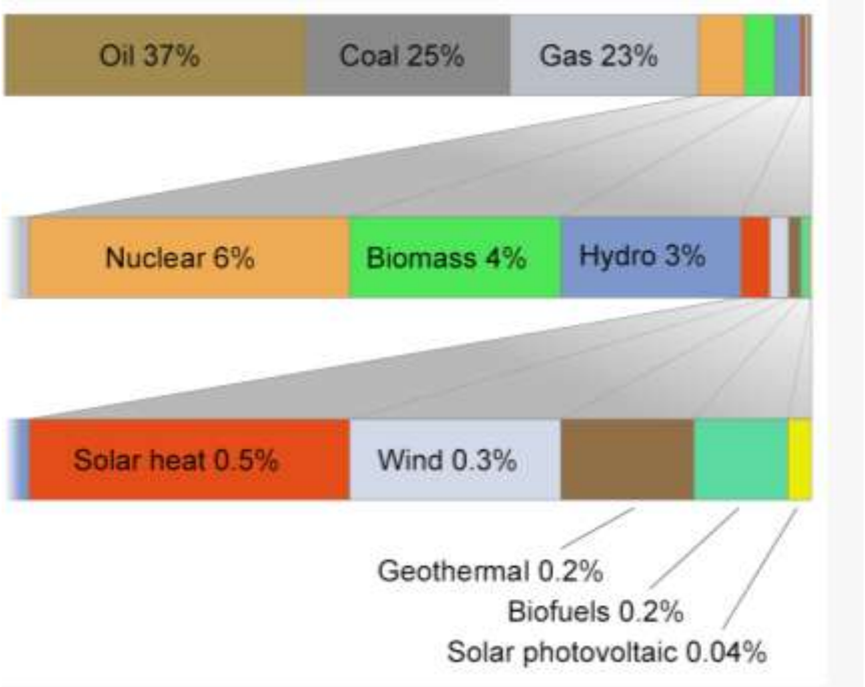
Alexander Telengator and Arkal Shenoy
General Atomics

30th Annual CNS Conference

GENERAL ATOMICS

WORLD ENERGY COMPOSITION

- **Fossil fuels provide ~ 85% of World energy needs and are vital to meet this demand. Oil still provides almost 40% of the energy.**



- ***However, the world LIQUID oil reserves will be declining, with a negative economic impact.***

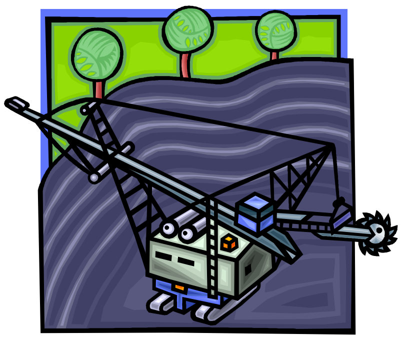
GENERAL ATOMICS

Oil Sands Extraction is an alternative to traditional oil recovery

- Oil Sands is a viable alternative to traditional oil recovery
- Canada has estimated oil reserves of 315 billion barrels in the Athabasca Oil Sands:
  - *World liquid oil reserves estimated < 1.0 trillion barrels.*
  - *50% of these liquid reserves are in the Middle East.*
- It has also been estimated that US has 30 billion barrels in Tar Sands
- Oil sands are currently producing *almost one million barrels of oil per day* with production rate steadily growing

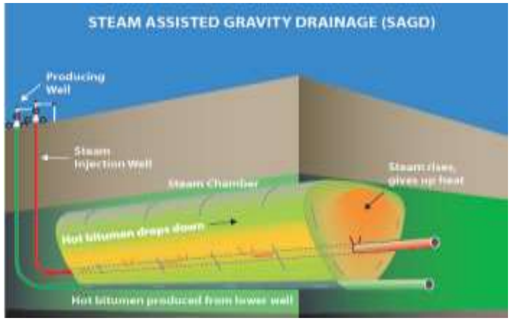
BUT - there are growing environmental concerns about oil extraction from Oil Sand Reserves

- **Most current oil extraction from Oil sands is by strip mining:**
  - *Problems with CO_2 emissions and pollution.*
  - *The Canadian government is likely to impose very strict clean air and pollution requirements.*



***But only ~20% of the Oil Sands reserve can be extracted by strip mining*.**

- **In-situ techniques (e.g., Steam Assisted Gravity Drainage or SAGD) are required to access the majority of the reserves.**
  - *However, currently these methods burn natural gas and still produce large amounts of CO_2.*
  - *For example, a 30,000 bpd Natural Gas SAGD process can produce a million tons of CO_2 every year.*



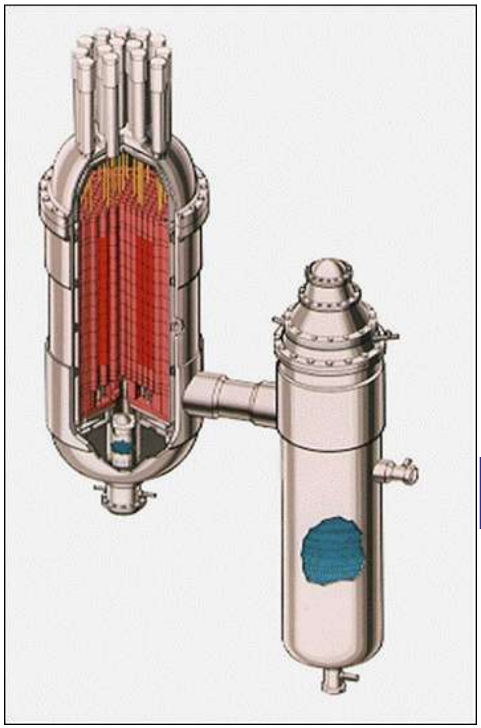
Coupling MHR with Oil Recovery from Tar Sands by Steam Assisted Gravity Drainage (SAGD)

The Modular Helium Reactor (MHR) can produce:

The high-temperature, high-pressure steam required for oil sands extraction applications;

The required electricity

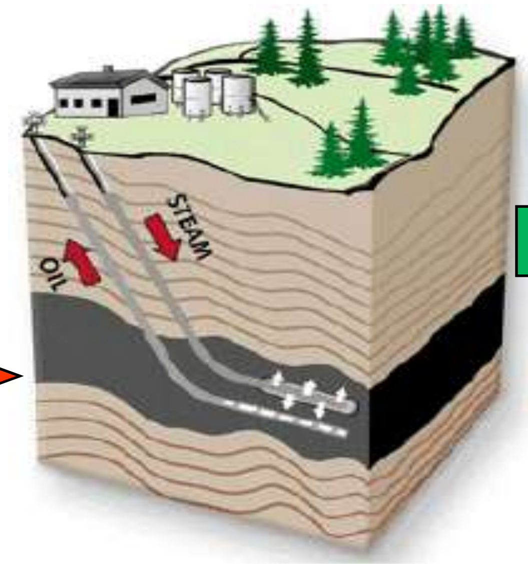
30,000 bbls of bitumen per day with Expansion possibility



25 MWe for plant needs

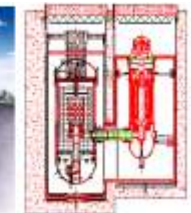
Steam for well injection

1400 psi at 585°F,



Potential for hydrogen production for Distillation.

HTGR Experience Dates Back to the Middle 1960s

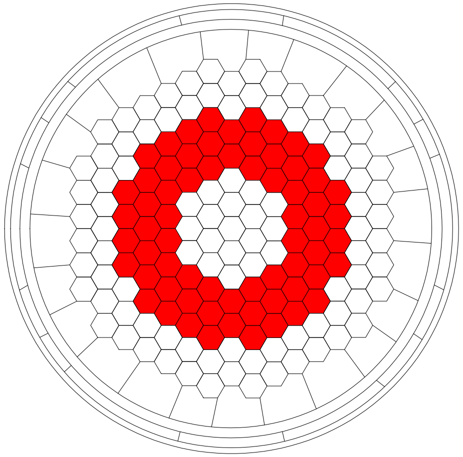
							
	Peach Bottom 1 **1966-1974**	**Fort St Vrain** **1976-1989**	**THTR** **1986-1989**	**Dragon** **1966-1975**	**AVR** **1967-1988**	**HTTR** **2000-**	**HTR-10** **2003-**
Power Level: **MW(t)**	115	842	750	20	46	30	10
MW(e)	40	330	300	-	15		--
Coolant: **Pressure, Mpa**	2.5	4.8	4	2	1.1	4	3
Inlet Temp, ^{o}C	344^{o}C	406^{o}C	250^{o}C	350^{o}C	270^{o}C	395^{o}C	250^{o}C/300^{o}C
Outlet Temp, ^{o}C	750^{o}C	785^{o}C	750^{o}C	750^{o}C	950^{o}C	850^{o}C/950^{o}C	700^{o}C/900^{o}C
Fuel type	$(U\text{-}Th)C_2$ PyC coated particles	$(U\text{-}Th)C_2$ TRISO	$(U\text{-}Th)O_2$ TRISO	$(U\text{-}Th)C_2$ PyC particles	$(U\text{-}Th)O_2$ TRISO	$(U\text{-}Th)C_2$ PyC particles	$(U\text{-}Th)O_2$ PyC particles
Peak fuel temp, ^{o}C	~1000^{o}C	1260^{o}C	1350^{o}C	~1000^{o}C	1350^{o}C	~1250^{o}C	
Fuel form	Graphite compacts in hollow rods	Graphite Compacts in Hex blocks	Graphite Pebbles	Graphite Hex blocks	Graphite Pebbles	Graphite compacts in Hex	Graphite Pebbles

*** More than 30 CO2-cooled, graphite-moderated reactors have been built and 10 are nowoperating in the United Kingdom for power production.*

TRISO particles are fuel kernels coated with SiC and PyC

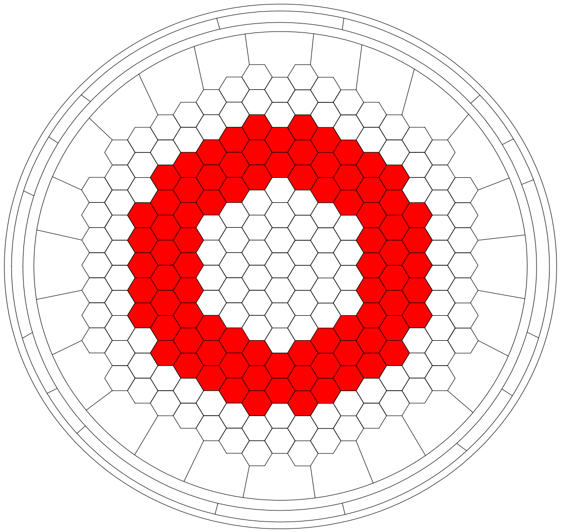
FLEXIBLE REACTOR DESIGN TO MEET DIFFERENT POWER NEEDS

350 MW(t)



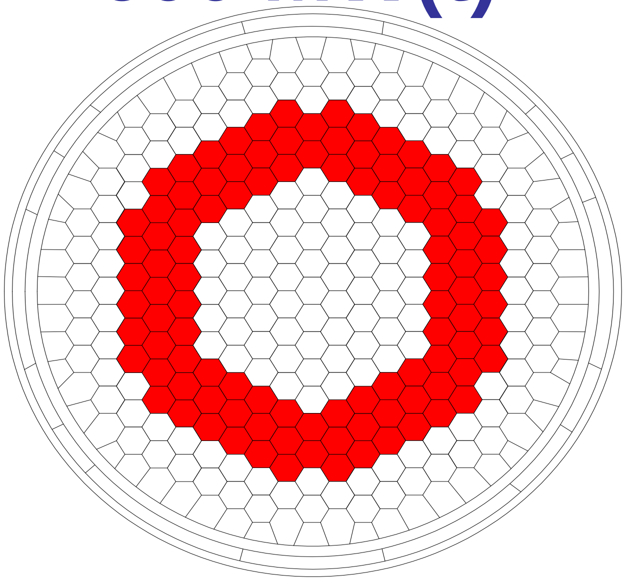
66 Columns
660 Elements

450 MW(t)



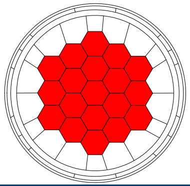
84 Columns
840 Elements

600 MW(t)



102 Columns
1020 Elements

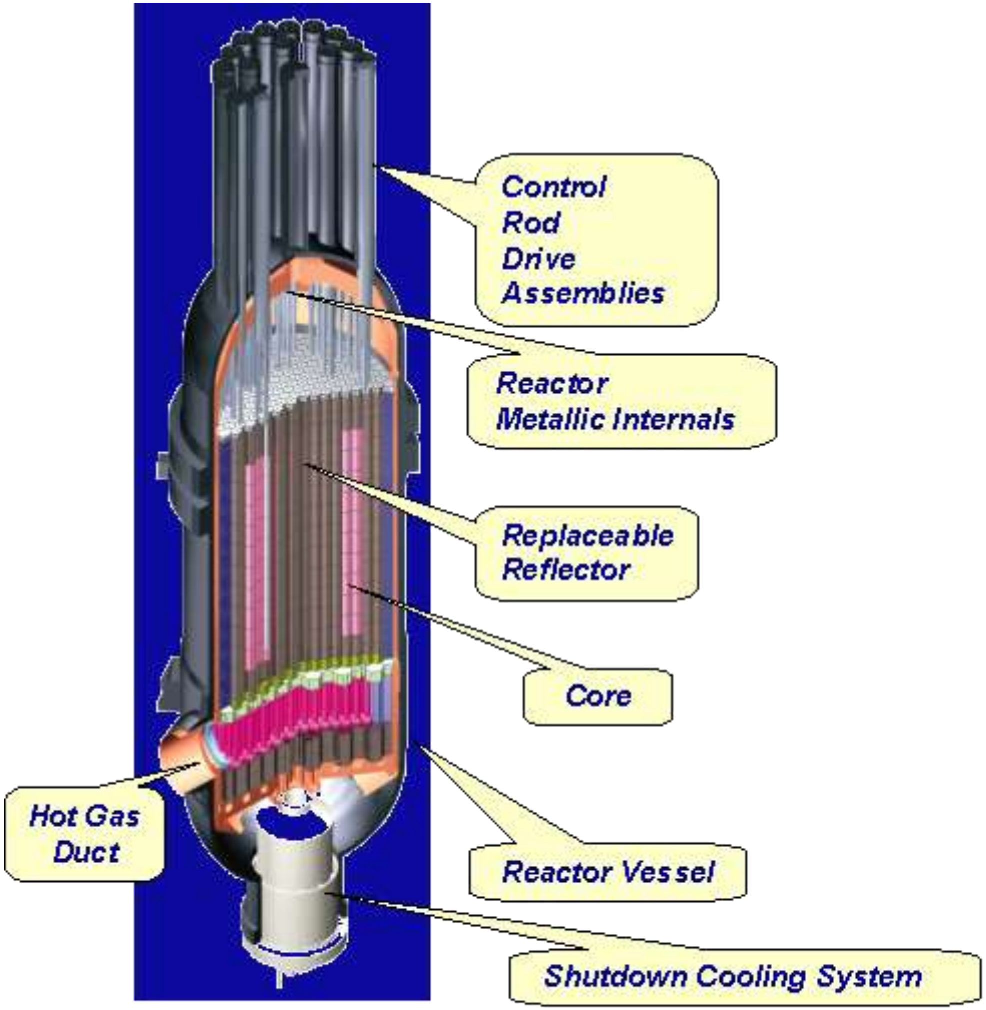
25 MW(t)



19 Columns
57 Elements

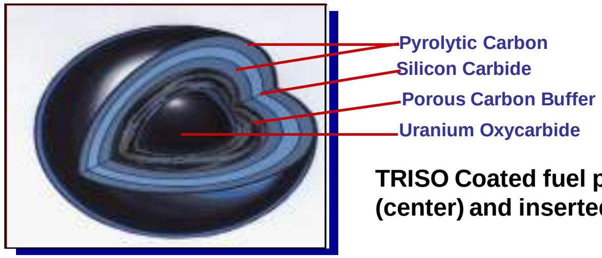
MHR Design Features Are Well Suited for Oil Extraction

- **Passive Safety**
  - No active safety systems required
  - No evacuation plans required
- **No CO_2 emission**
- **Competitive Economics**
- **High Thermal Efficiency**
- **Siting Flexibility**
  - Lower waste heat rejection, reduced water cooling requirements
- **High-Temperature Capability with Flexible Energy Outputs**
  - Electricity
  - Hydrogen
  - Synfuels, etc.
- **Flexible Fuel Cycles**
  - LEU, HEU, Pu, TRU, Thorium



Inherent Safety Features of the MHR

Ceramic fuel retains radioactive materials up to ~2000˚C



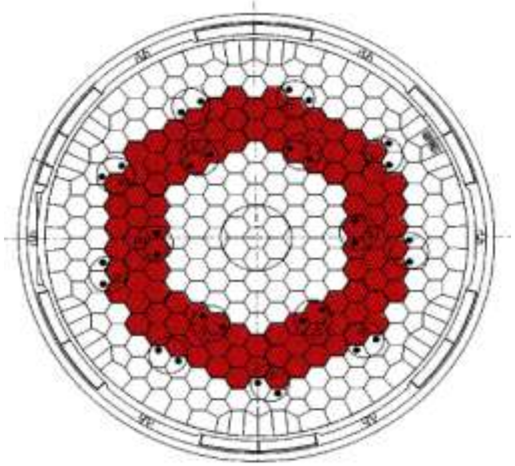
TRISO Coated fuel particles (left) are formed into fuel rods (center) and inserted into graphite fuel elements (right).

PARTICLES

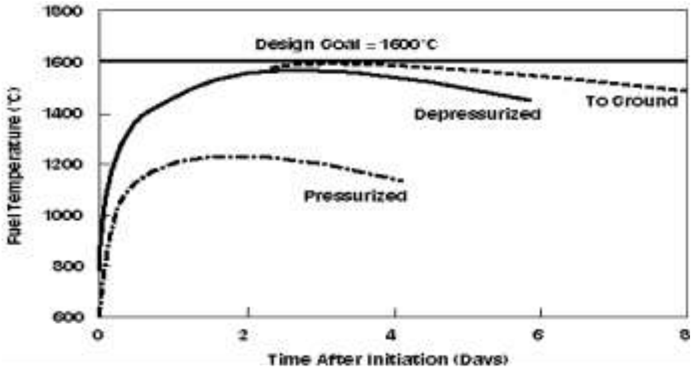
COMPACTS

FUEL ELEMENTS

Heat removed passively without primary coolant

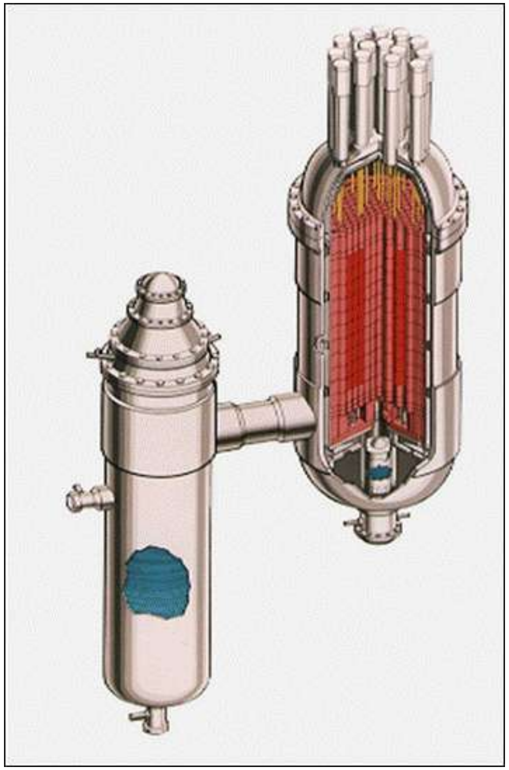


Fuel temperatures remain below design limits during loss-of-cooling events



Parameters of the 350 MW(t) MHR

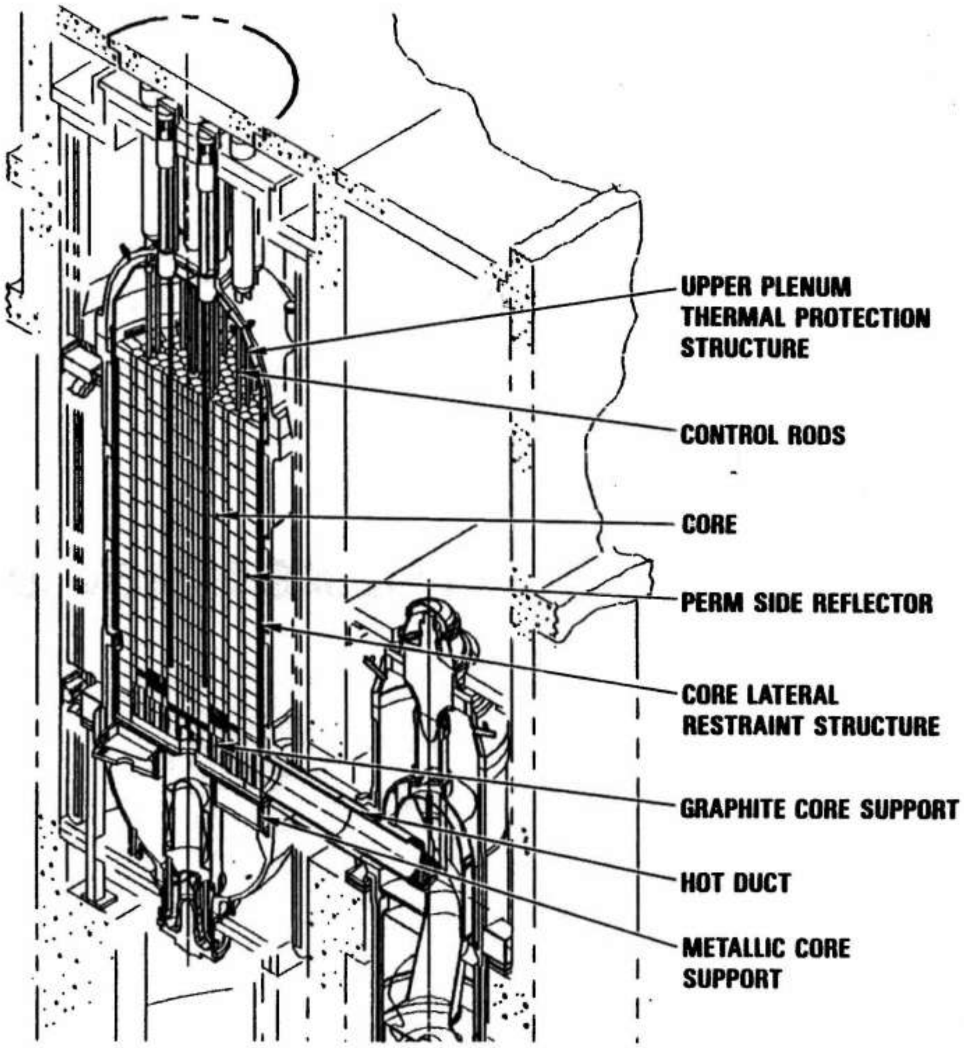
The 350 MW(t) MHR GENERATES STEAM AT 1000° F (540° C) AND 2500 PSI (17 Mpa)



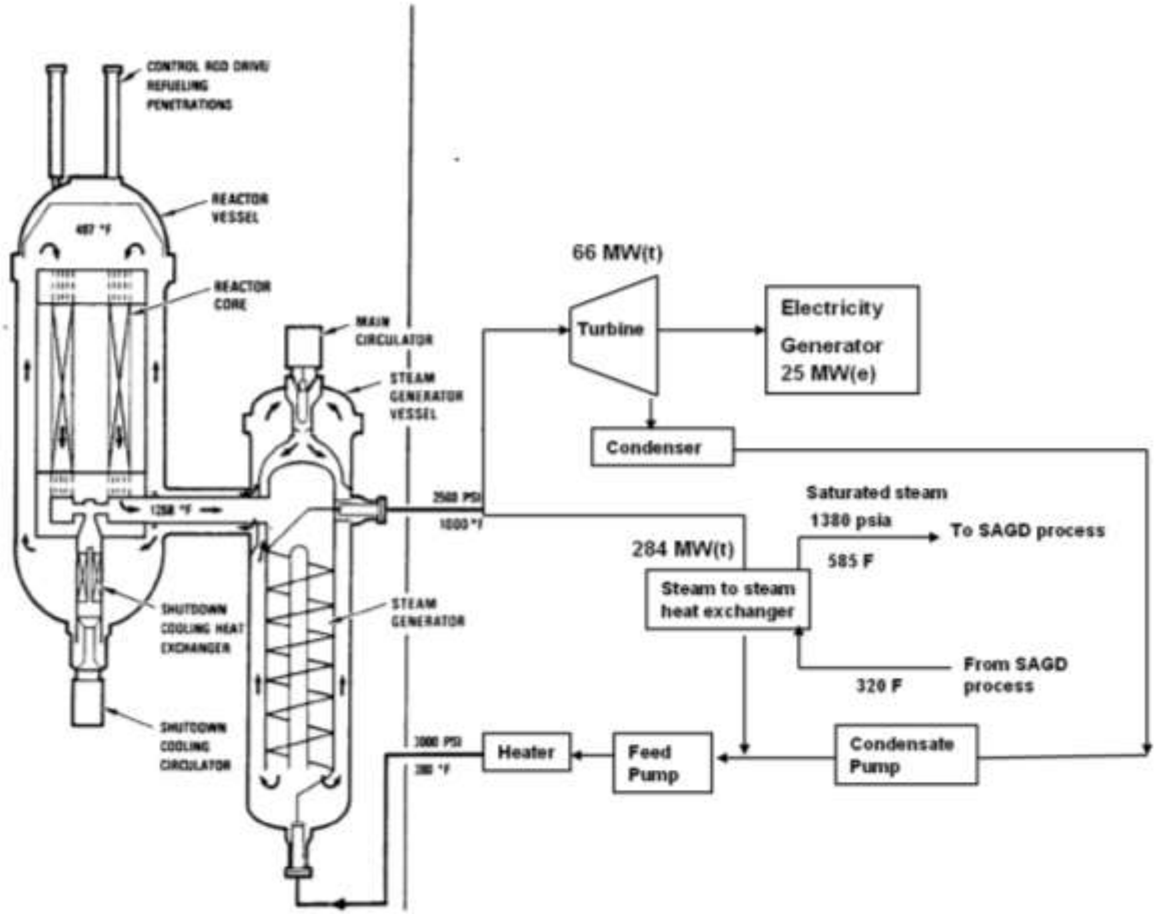
Cold helium temperature	259 C
Hot helium temperature	687 C
Helium pressure at rated power	6.39 MPa
Fuel elements	Prismatic hex blocks
Fissile material	Uranium oxycarbide
Fertile material	ThO_2
Power density	5.9 W/cm^3
Active core configuration	66-column annulus, 10-blocks high

GENERAL ATOMICS

350 MW(t) MHR: Schematic of the Reactor System



The MHR Cycle Diagram for Oil Recovery from Tar Sands



PS/C-MHR Plant

- Similar to heavy Oil Recovery System.
- 30 year oil sands plant life.
- Delivers saturated steam at 585° F and 1400 psia.
- Extracts oil in-situ using Steam Assisted Gravity Drainage (SAGD)

Produces ~ 25 MWe Electricity for site needs.

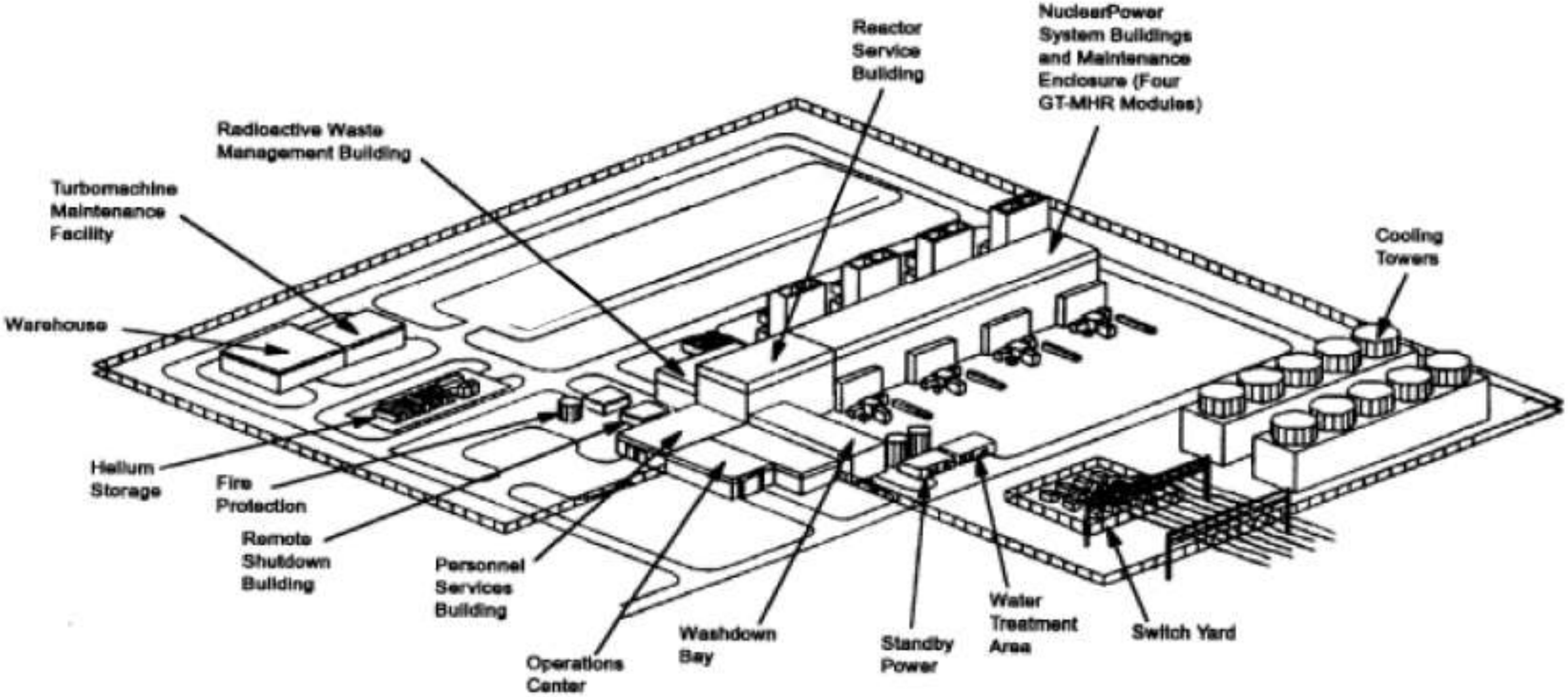
Steam to Oil Ratio (SOR) assumed ~2.5

Possibility for Expanded SAGD Plant

Steam Requirements have been estimated for expanded SAGD plants

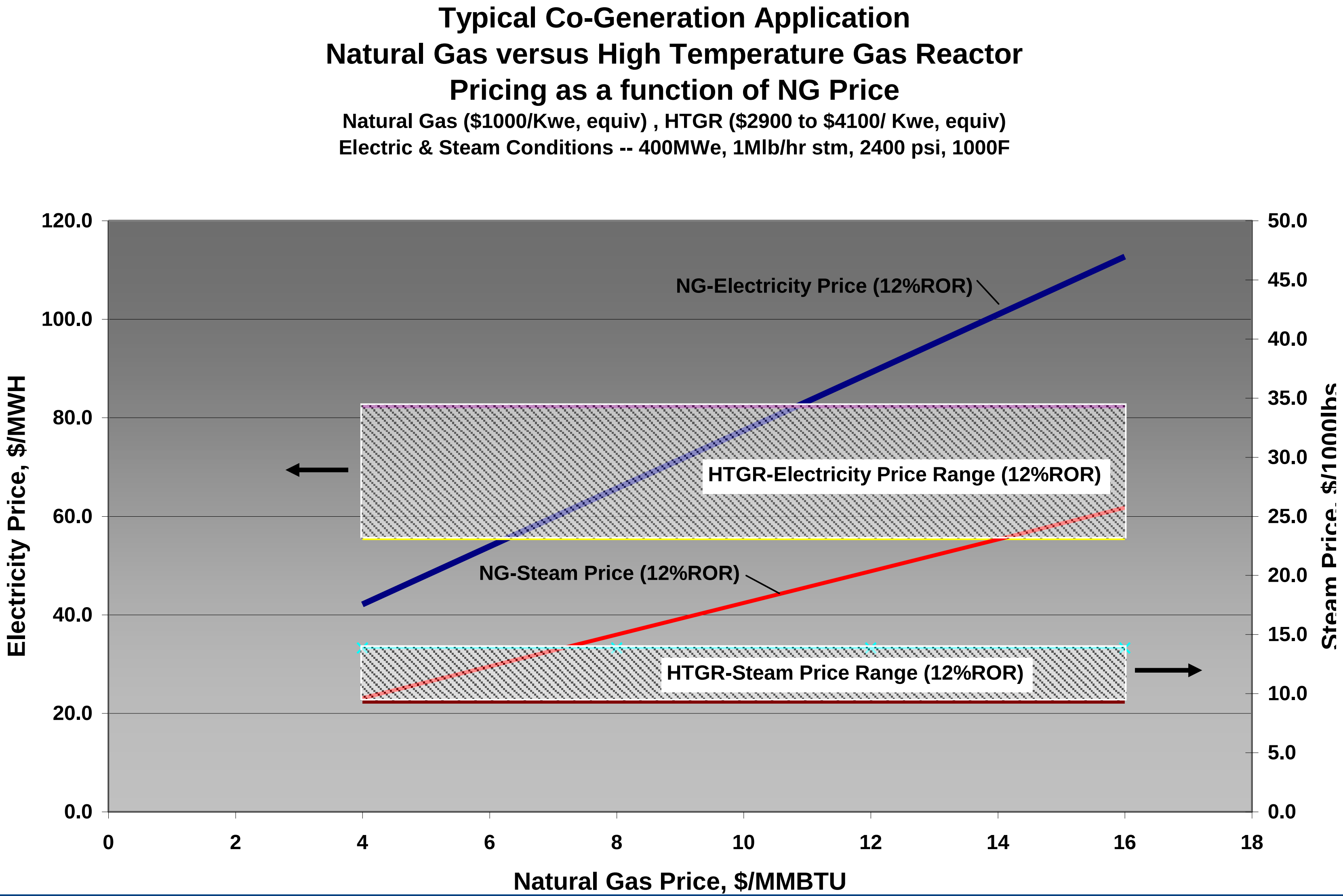
Plant Size (BPD)	Number of 350 MW_t MHR Modules	Thermal Power (MW_t)	Feed water Volume Rate, (m^3/d)	Mass Rate (Million kg/d)
30,000	1	284	11,925	12
60,000	2	568	23,850	24
90,000	3	852	35,775	36
120,000	4	1136	47,700	48

FOUR-MODULE MHR PLANT



GENERAL ATOMICS

Electricity and Steam Pricing Comparison – by Entergy



Next Generation Nuclear Plant (NGNP) Project

- Project established by Energy Policy Act of 2005
- INL leading project under direction of DOE
- Current goal is for NGNP startup by 2021
- Current Modified NGNP Objective – Co-generation of Electricity and Process Steam

GENERAL ATOMICS

Evolving NGNP Applications

HTGR technology is to be demonstrated through US DOE NGNP Program

The Potential Market…

High Temperature Gas-cooled Reactor Energy End-Users

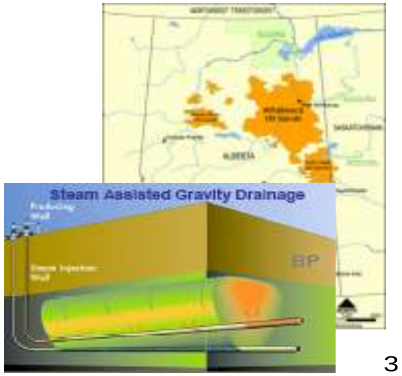
(Potential Number of 300-600 MW thermal HTGRs)

Petrochemical (150)

Petroleum Refining (50-100)

Coal-to-Liquids (100s)

Fertilizers/Ammonia (100+)



3

Oil Sands/Shale (200+)

Other Process Steam and Process Heat Applications

General Atomics considered other process steam and high-temperature process heat applications of the MHR.

Process Steam Applications:

- Catalytic Coal Gasification
- Direct Coal Liquefaction
- Coal Cleanup Process

High-Temperature Process Heat Applications:

- Hydrogen generation with subsequent synfuel production
- Oxygen generation with subsequent oxy-fire use and/or high-temperature gasification
- Oil shale extraction

Conclusions

- The Modular Helium Reactor (MHR) is a viable option for providing carbon-free process steam and electricity for oil sands extraction

- MHR application for steam production for a 30,000 barrels per day SAGD plant saves ~29 Million SCF of natural gas usage and eliminates over 1700 tons of CO_2 emission per day.