NGNP **Industry Alliance**
Clean Sustainable Energy for the 21st Century

High Temperature Gas-Cooled Reactors—Now More Than Ever!

Dr. Finis SOUTHWORTH
Chief Technology Officer
AREVA Inc.

On behalf of the NGNP Industrial Alliance, LLC

Washington DC Section ANS
Rockville, MD
April 12, 2011

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Roadmap

- What is NGNP ?
- What is the NGNP Alliance? – 2006-present
- EPACT 2005 and NGNP activities to date
- HTR / NGNP design description
- Economics of HTRs
- Safety characteristics
- A little more about Fukushima Daiichi topics
- Q&A

Next Generation Nuclear Plant History

- Next Generation – Generation IV
- Generation IV Roadmap – December 2000 to September 2002
- VHTR Selected as lead concept for US Demonstration-
  - New missions of hydrogen production and process heat applications
  - Most passively safe of all candidate Generation IV reactor concepts
- NGNP drafted into Energy Policy Act January 2003
- EPACT required 31 months to pass-- August 8, 2005, authorizing "$1.5 Billion through 2014, and such sums as may be needed subsequently for construction"
- EPACT 2005 called for DOE to partner with an Industry Alliance to partner for the demonstration and deployment of the NGNP.
- The NGNP Industrial Alliance was first formed in May 2006.

NGNP Industry Alliance

Clean Sustainable Energy for the 21st Century

NGNP Industrial Alliance, LLC

Dow

ConocoPhillips

Entergy

PotashCorp
Helping Nature Provide

Chevron
Human Energy

AREVA

Westinghouse

EASTMAN

B&W thebabcock&wilcoxcompany
a McDermott company

Shaw

EPRI ELECTRIC POWER RESEARCH INSTITUTE

PTAC

SGL

Industry Alliance

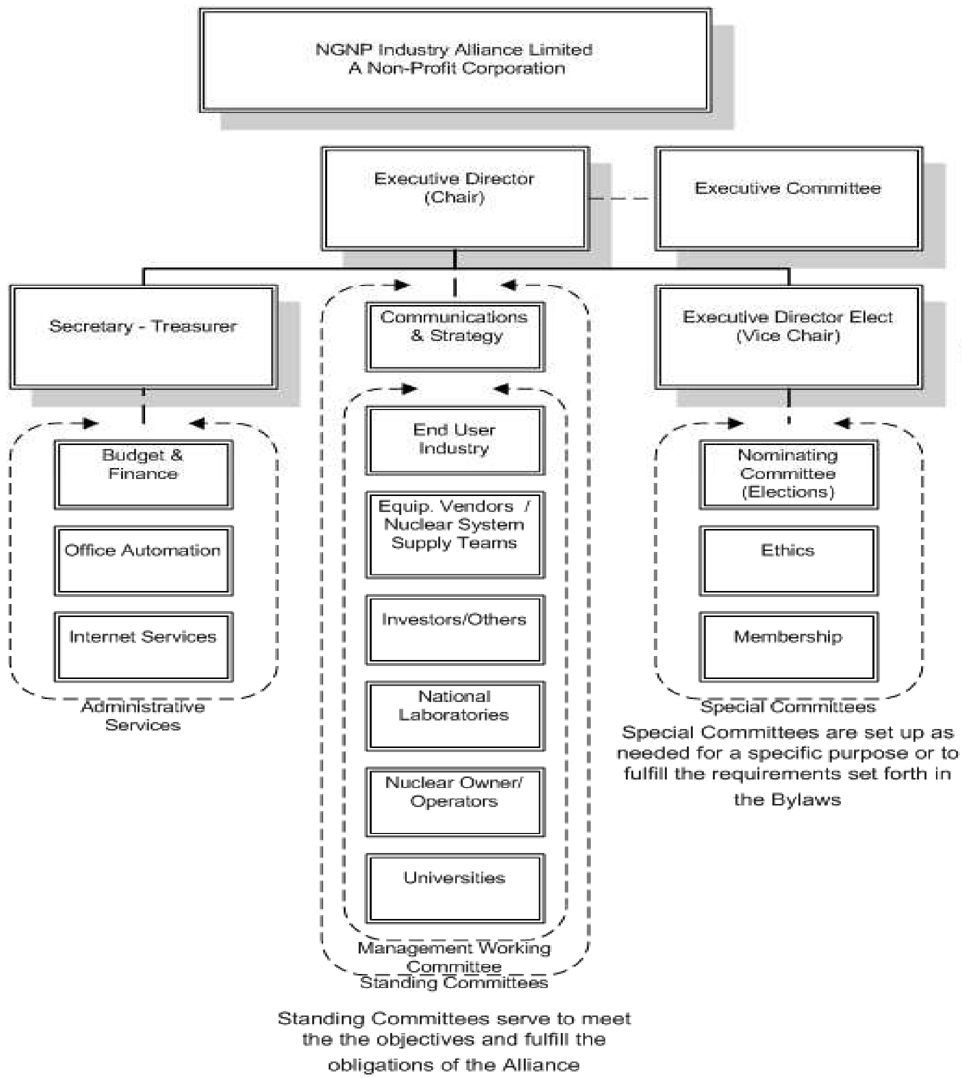
Clean Sustainable Energy for the 21st Century

\- Mission -

"To work with Government to commercialize High Temperature Gas-cooled Reactor technology expanding the use of clean nuclear energy and significantly reducing the dependence on premium fossil fuels."

Communications & Strategy Committee
Recommend the following:
Keith Belton / Peter Molinaro - Dow Chemical
Allison Graves / George O'Connor – Entergy
Mark Haynes – Concordia Power

Management Working Committee:
Finis Southworth – AREVA
Fred Moore – Dow Chemical
Don Halter – ConocoPhillips
TBD - Eastman Chemical
John Mahoney – Entergy
Phil Hildebrandt – BEA INL
Layla Sandell – Westinghouse
James Hobbs – B&W



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HTR Design

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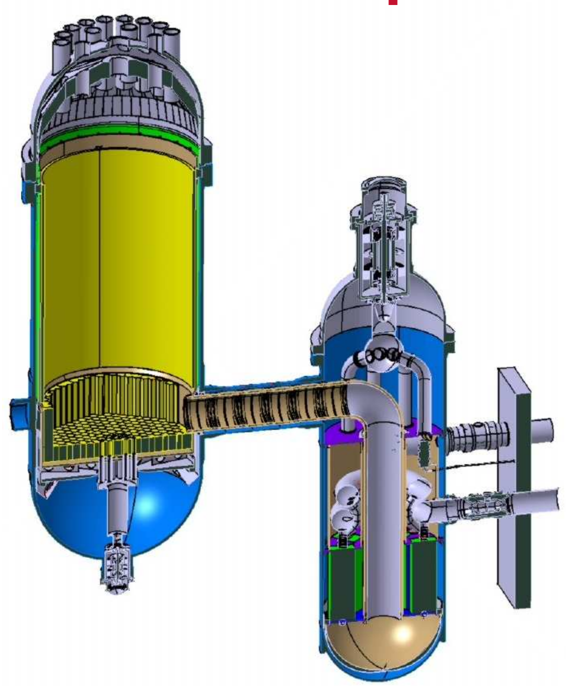
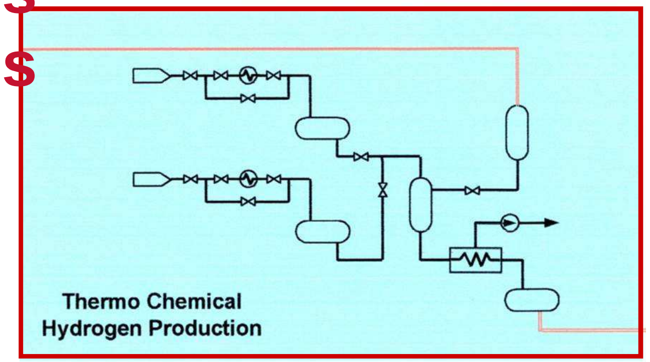
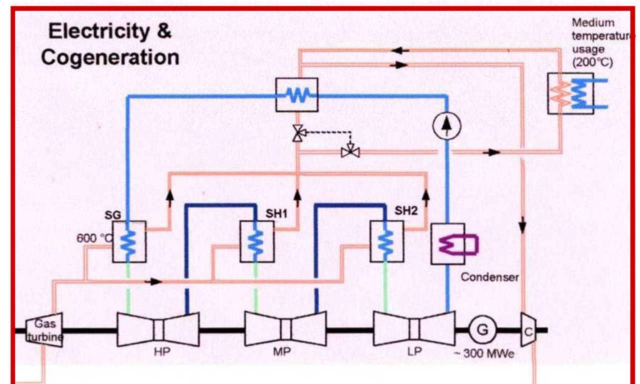
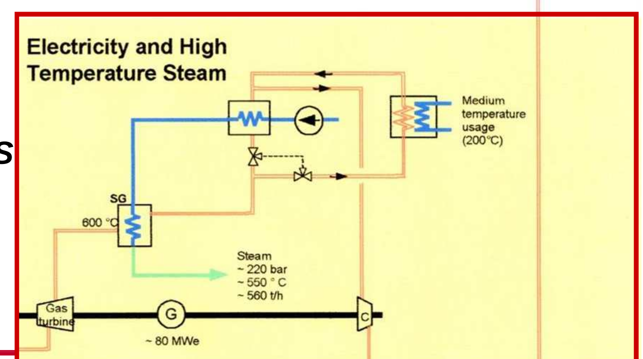
Long Term High Temp Gas Reactors For a Spectrum Of Applications







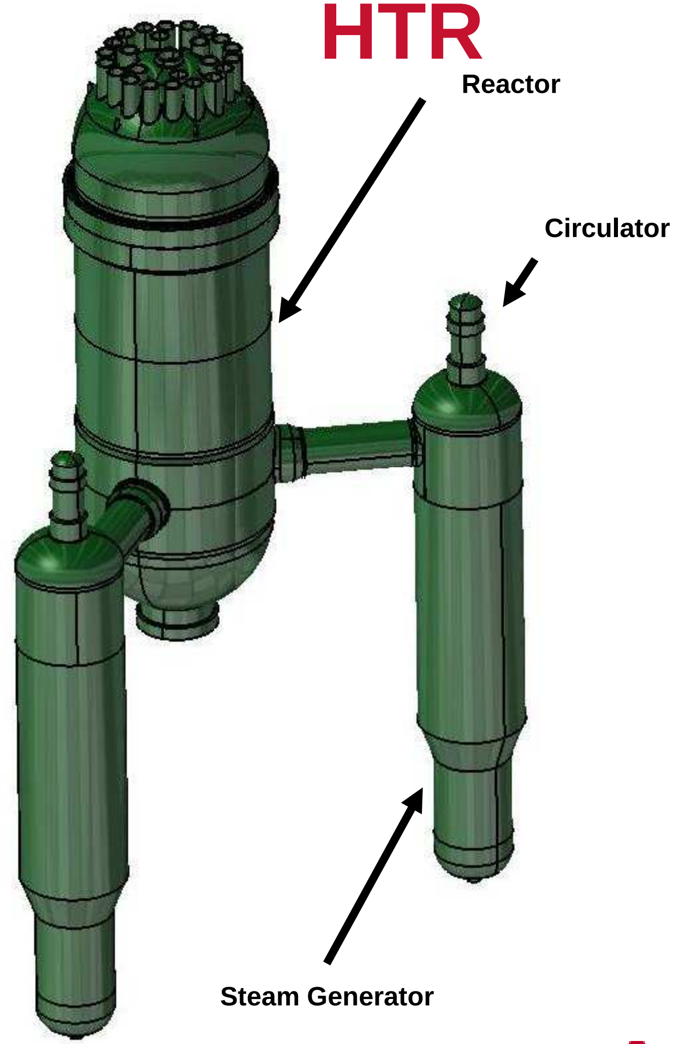


ANTARES

- ***SIMPLE***
- ***LOW COST***
- ***COMBINED BRAYTON AND RANKINE CYCLES FOR HIGH EFFICIENCY***
- ***PASSIVELY SAFE***
- ***SUPPORTS H_2 PRODUCTION***

Key Features of AREVA Near-Term HTR

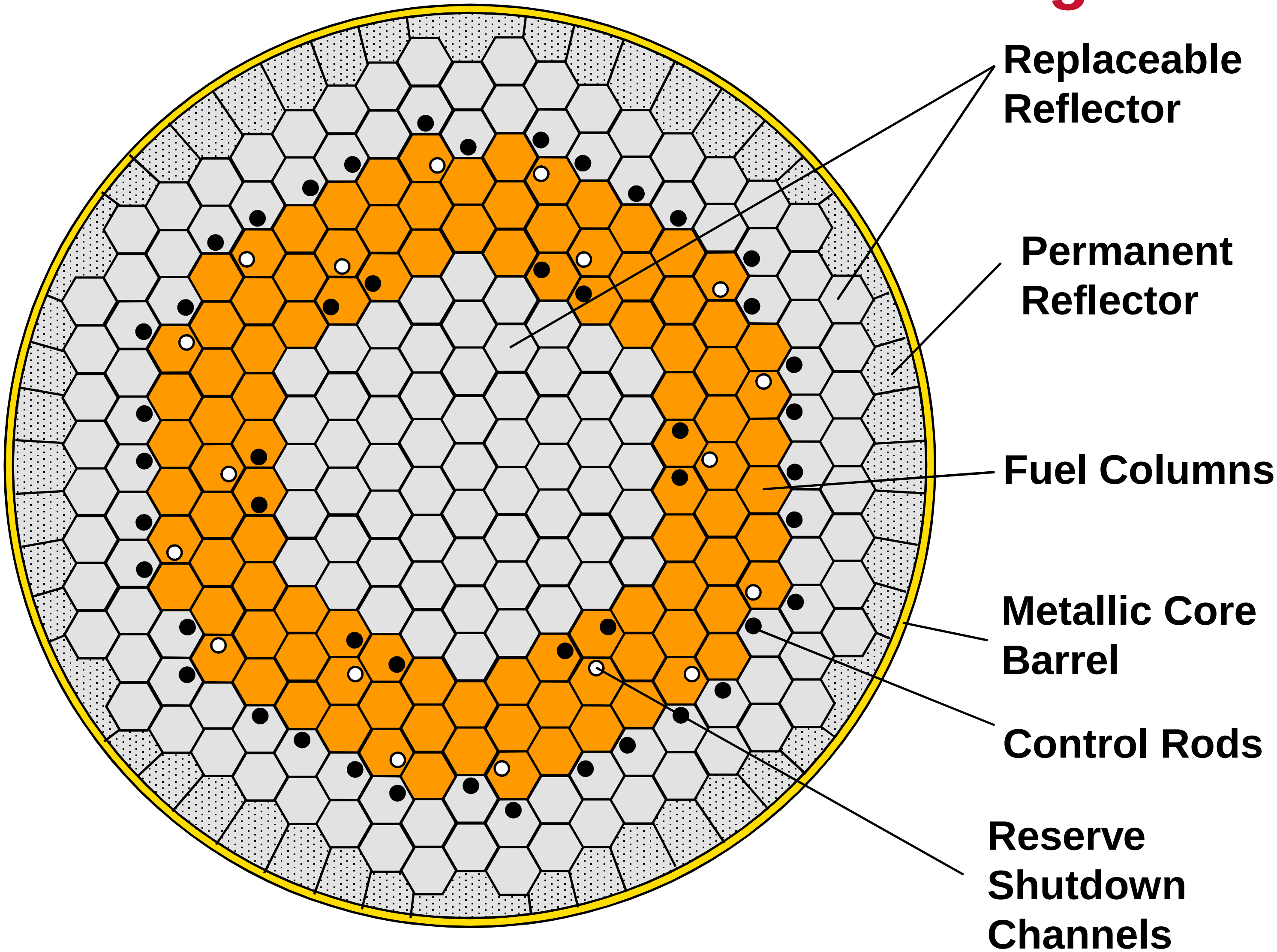
- Prismatic block annular core
- Conventional steam cycle
- Modular reactors
- Inherent safety characteristics
  - Passive decay heat removal
  - Large thermal inertia
  - Negative reactivity feedback
- Minimal reliance on active safety systems
- Sized to minimize steam production cost
- Fully embedded reactor building
  - Partially embedded alternative possible



Nominal Operating Parameters

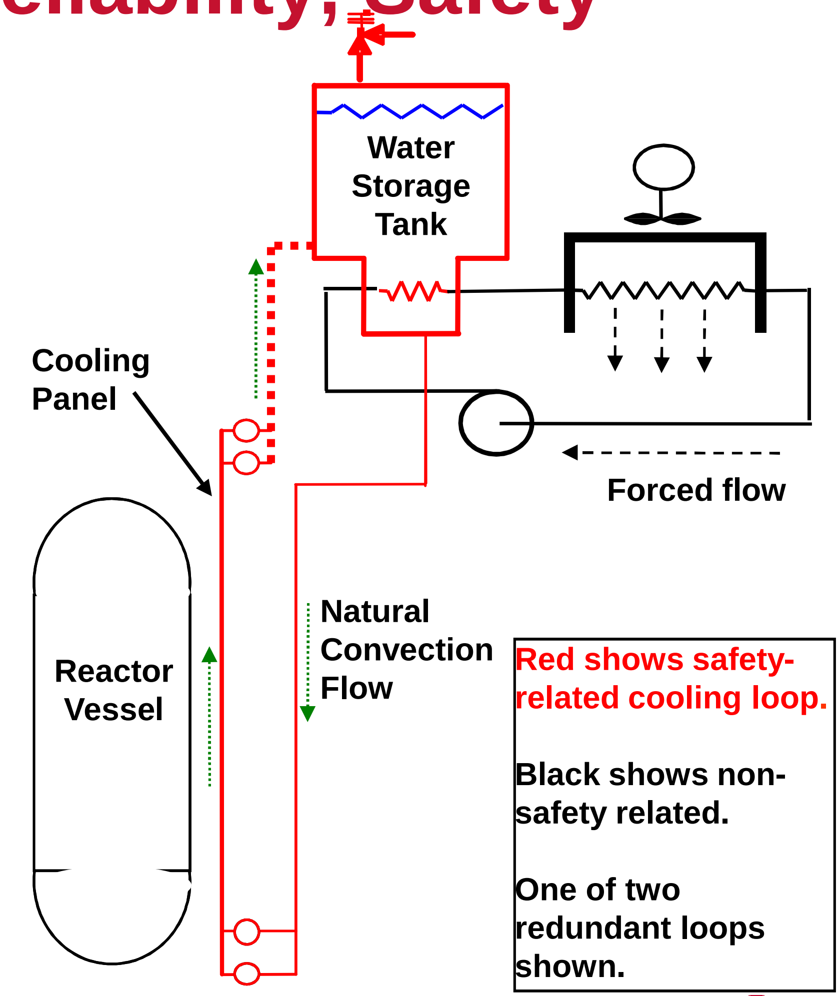
Fuel type	TRISO particle
Core geometry	102 column annular 10 block high
Reactor power	625 MWt
Reactor outlet temperature	750°C
Reactor inlet temperature	325°C
Primary coolant pressure	6 MPa
Vessel Material	SA 508/533
Number of loops	2
Steam generator power	315 MWt (each)
Main circulator power	4 MWe (each)
Main steam temperature	566°C
Main steam pressure	16.7 MPa

Annular Core Arrangement



Cooling Systems Optimized for Reliability, Safety

- **Main heat transport system**
  - **Established helical coil steam generator technology**
  - **Electric motor circulator with magnetic bearings**
- **Shutdown cooling system**
  - **Active system**
  - **Maximizes plant availability**
    - Maintenance
    - Rapid accident recovery
- **Reactor cavity cooling system**
  - **Safety related heat removal system**
  - **Passive cooling of vessel and surrounding cavity (operates continuously – safety-related)**
  - **Active cooling of water storage tank during normal operation (non-safety)**



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The Dow Perspective

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About Dow

- Diversified chemical company, harnessing the power of science and technology to improve living daily
- Founded in Midland, Michigan, in 1897
- Supplies more than 5,000 products to customers in 160 countries
- Annual sales of $45 billion
- 52,000 employees worldwide
- Committed to Sustainability

Dow Energy Uses

900,000 BBL Oil Eqiv / Day Or 0.3% of the World's Energy

Oil & Gas

Feedstock
Ethane, Propane
Butane, Naphtha

Steam

Power

600 trillion Btu/yr

Dow Energy Plan

Four fundamentals make the transition to a sustainable energy future possible.

- **Aggressively pursue energy efficiency and conservation**
- **Increase, diversify and optimize hydrocarbon energy and feedstock supplies**
- **Accelerate development of alternative and renewable energy and feedstock sources**
  - **Finally, Dow supports the federal government's efforts to provide financial support to enable leadership in advancing development of new nuclear power technologies. One promising example is the High Temperature Gas Reactor (HTGR), which has the potential to produce synthetic fuels and feedstocks when combined with gasification of coal or other domestic carbon sources.**
- **Transition to a low carbon economy**

Power, Heat & Steam Generation

- 4 GWs of self generated electricity
- More than 22 million pounds per hour of self generated steam
- Enormous direct fired process heating loads

Why HTGR?

- **Inherent safety – co location**
- **N-X reliable process heat & electricity**
- **Neutral cost without cost of carbon**
- **Addresses all key energy policy issues**
  - **Energy security**
  - **Carbon footprint**
  - **National security**
  - **Jobs**

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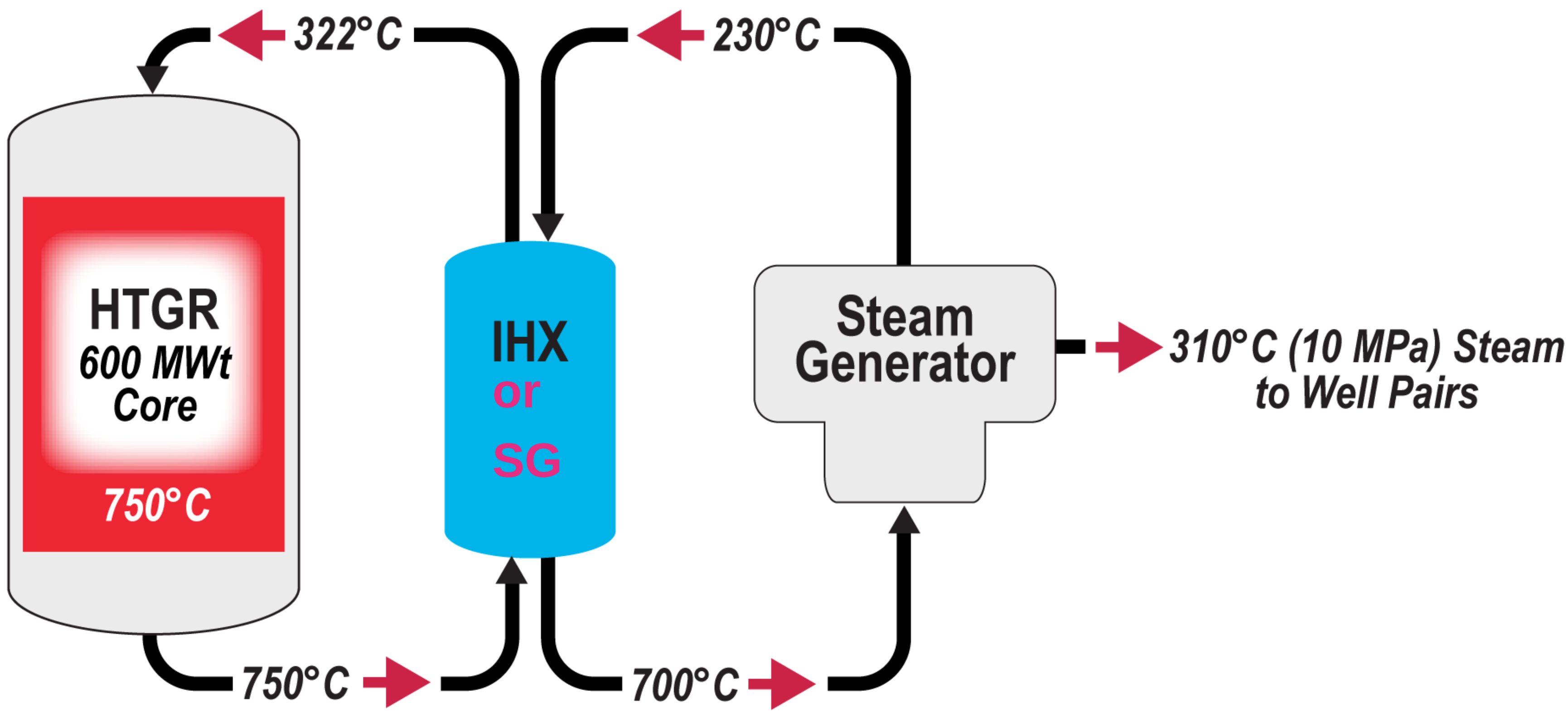
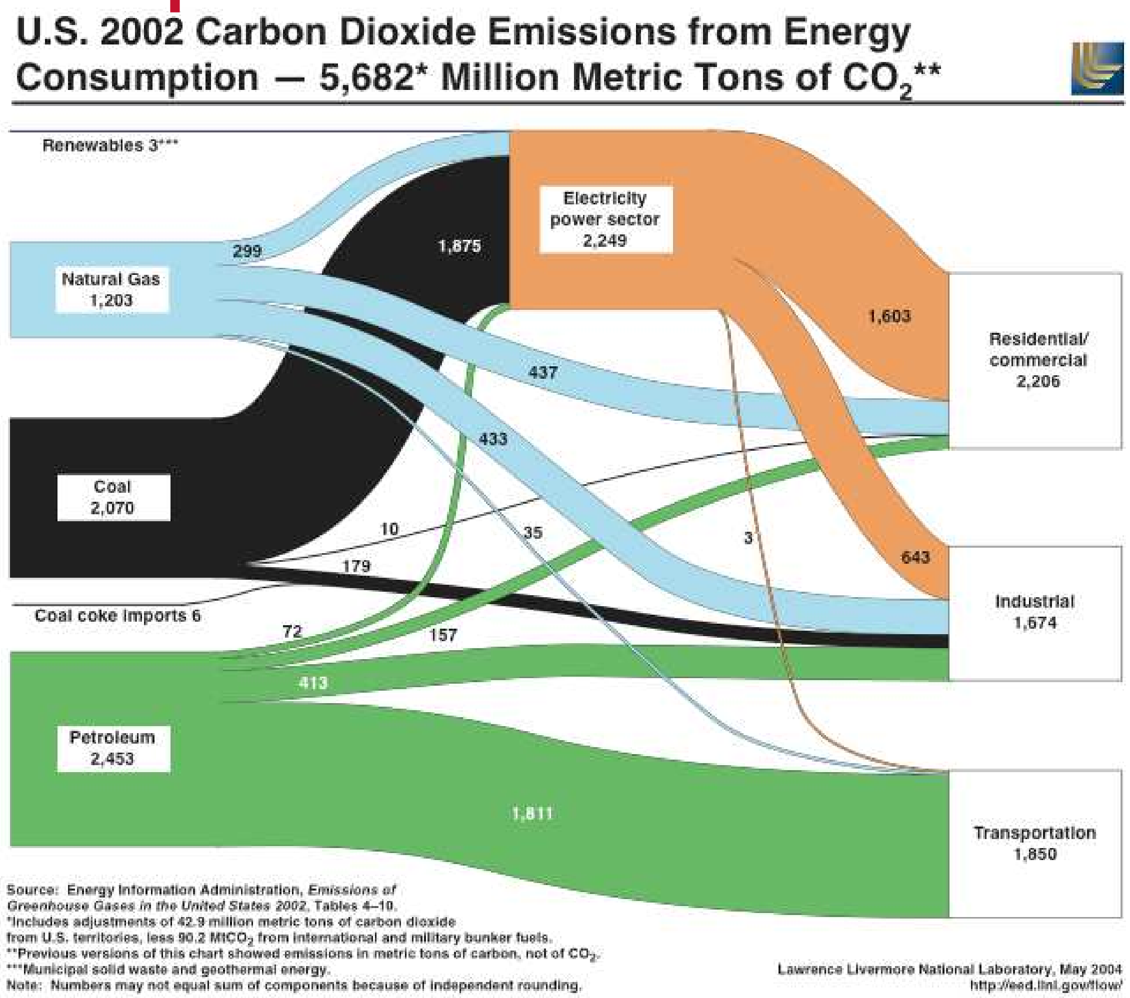
INL Economics Analysis of NGNP

HTGR Layout For SAGD Integration Modeling



In US coal for electricity and oil for transportation produce about 3/4 of the man-made CO_2



Substitution of electricity from nuclear for coal and hydrogen from nuclear for oil would reduce CO_2 release by 2/3

Process heat from nuclear could eventually replace the remaining 1/3

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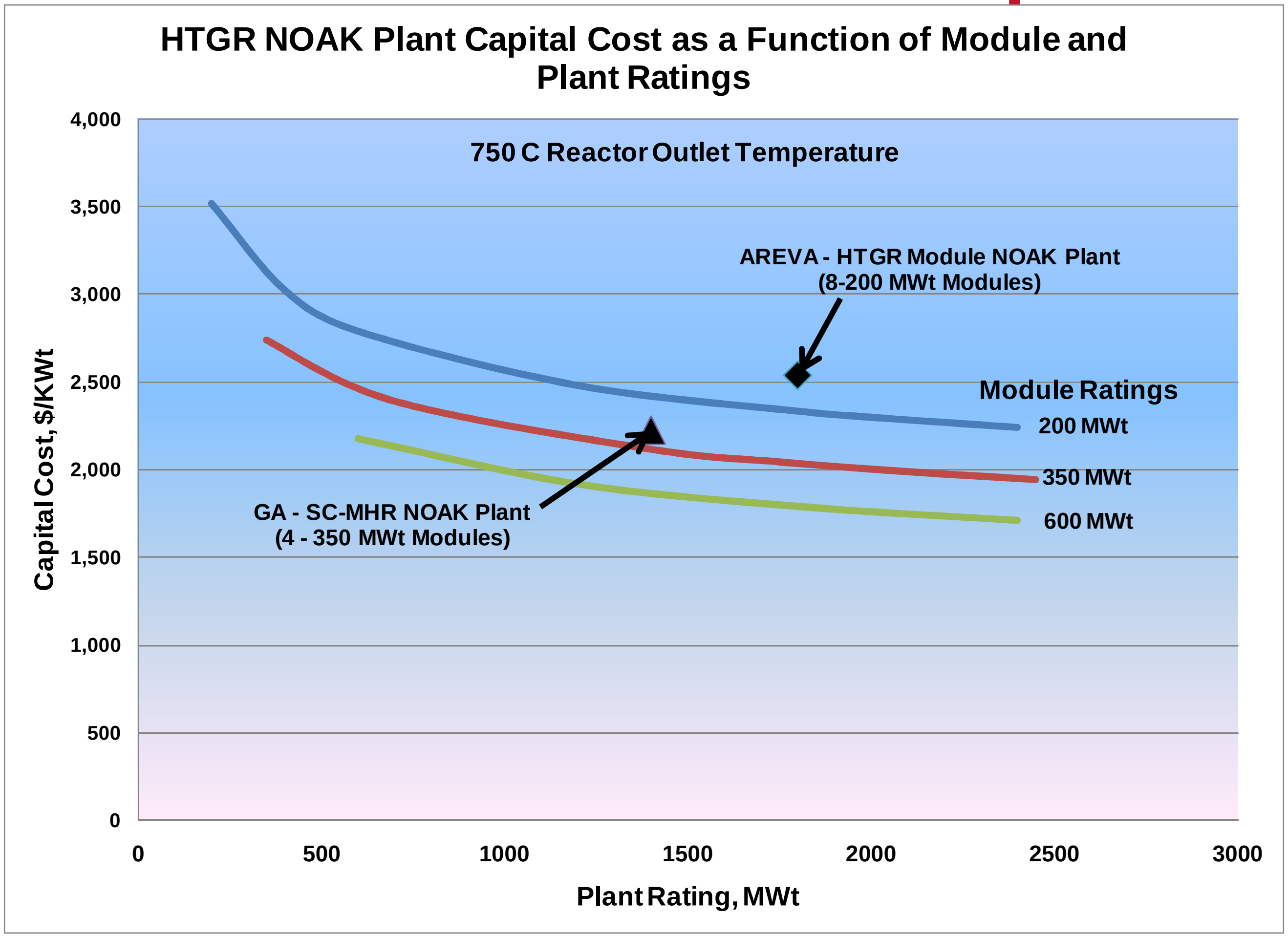
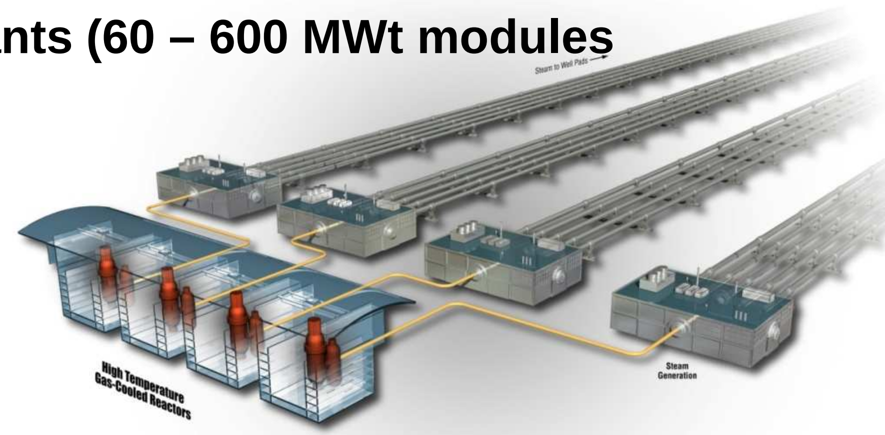
INL Plant Capital Cost Development



Full HTGR Integration for Bitumen Recovery

- **Assuming a central HTGR facility supplying 2,400 MWt of steam:**
  - **Bitumen recovery of 224,000 barrels per day**
  - **Reduction in natural gas consumption – 81.8 billion SCF/year**
  - **Reduction in CO_2 emissions – 5.3 million tons/year**
  - **Over 60 years this rate of steam supply from the HTGR plant would result in:**
    - Supplying 52 simultaneous well pads for 12 years each
    - Supplying 260 well pads over the life of the reactors
    - Covering 65,200 hectares of land
    - Reducing natural gas consumption by 4.9 trillion SCF
    - Reducing CO_2 emissions by 317 million tons
- **Estimate the potential for 15 plants (60 – 600 MWt modules**



Characteristics of Potential Markets, cont'd

Products & Markets, cont'd

Process Heat, Hydrogen & Oxygen

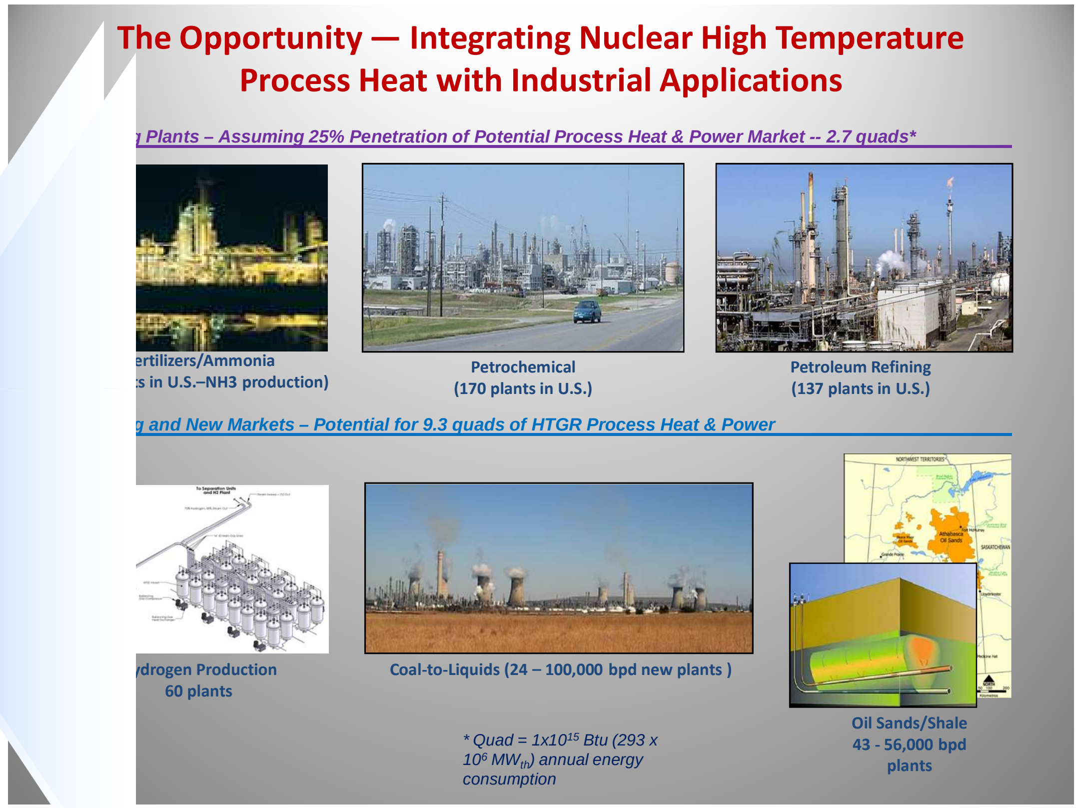
- Petro-chemical, Fertilizer, Refining (in addition to co-generation, e.g., cracking operations, direct ammonia production, hydrogenation)
- Merchant Hydrogen – 5.4MMtons (2005), separate from refining industry production and usage of hydrogen
- CTL/BTL (24 new 100,000 bpd plants)
  - Synthetic feedstock, transportation fuels (assumed that production would equal 25% of crude oil imports in 2008)

Electricity

- Substitute for Coal & Natural Gas Plants
  - Emissions reductions & saving natural gas resource

Size of the potential market

- **Petrochemical, Refining, Fertilizer/Ammonia market and other**
  - **Co-generation**
    - 75 GWt (125 – 600 MWt modules)
- **Oil Sands**
  - **Steam, Electricity & Hydrogen**
    - 36 GWt (60 -- 600 MWt modul
- **Hydrogen Merchant Market**
    - 40 GWt (67 – 600 MWt n



- **Synthetic Fuels & Feedstock**
  - **Steam, electricity, hydrogen**
    - 249 GWt (415 – 600 MWt modules)
- **Electricity**
  - **110 GWt; ~180 – 600 MWt modules**
  - **10% of the nuclear electrical supply increase required to achieve pending Government objectives for emissions reductions by 2050**

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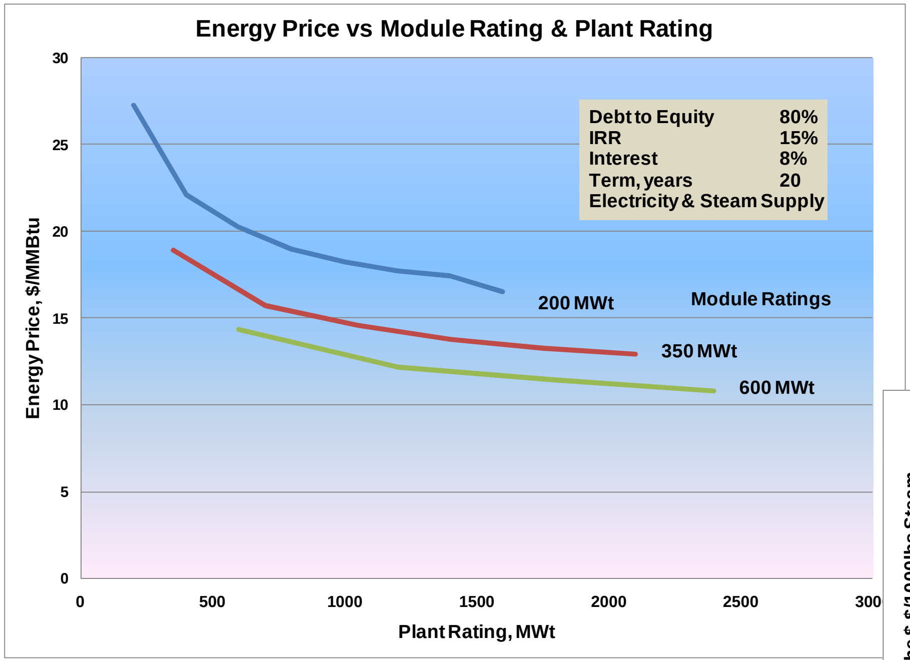
Economics Supplying Steam & Electricity



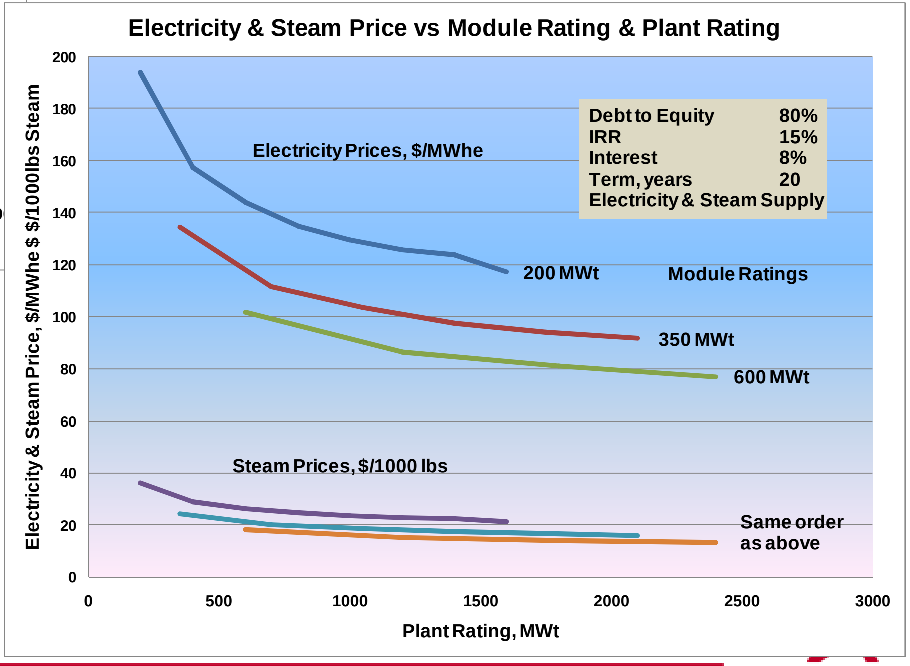
Equivalent Natural Gas Prices

(Maximum # of Modules)

200 MWt / 1600 MWt -- $10.8/MMBtu

350 MWt / 1400 MWt -- $8.3/MMBtu

600 MWt / 2400 MWt -- $6.8/MMBtu



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HTR Safety – A quick review

Safety Functions in NPPs

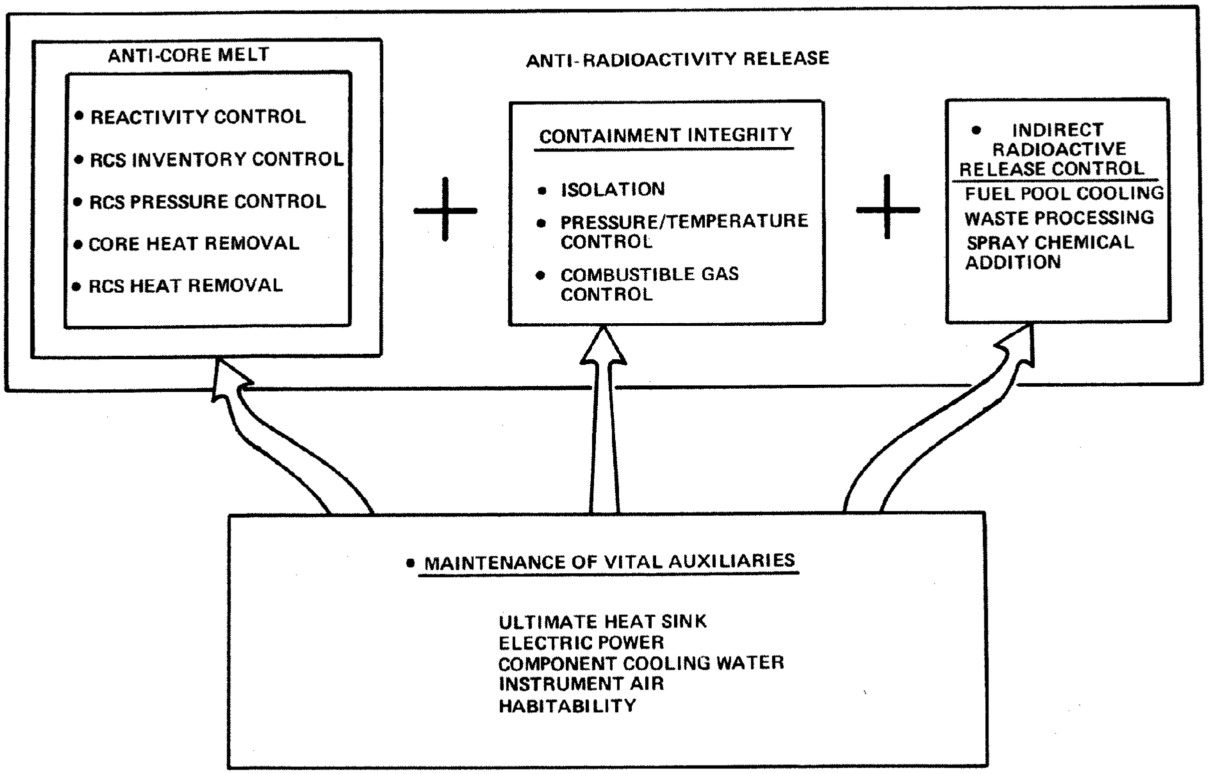

Fig. 1. Classes of safety functions.

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Safety Functions in HTGRs

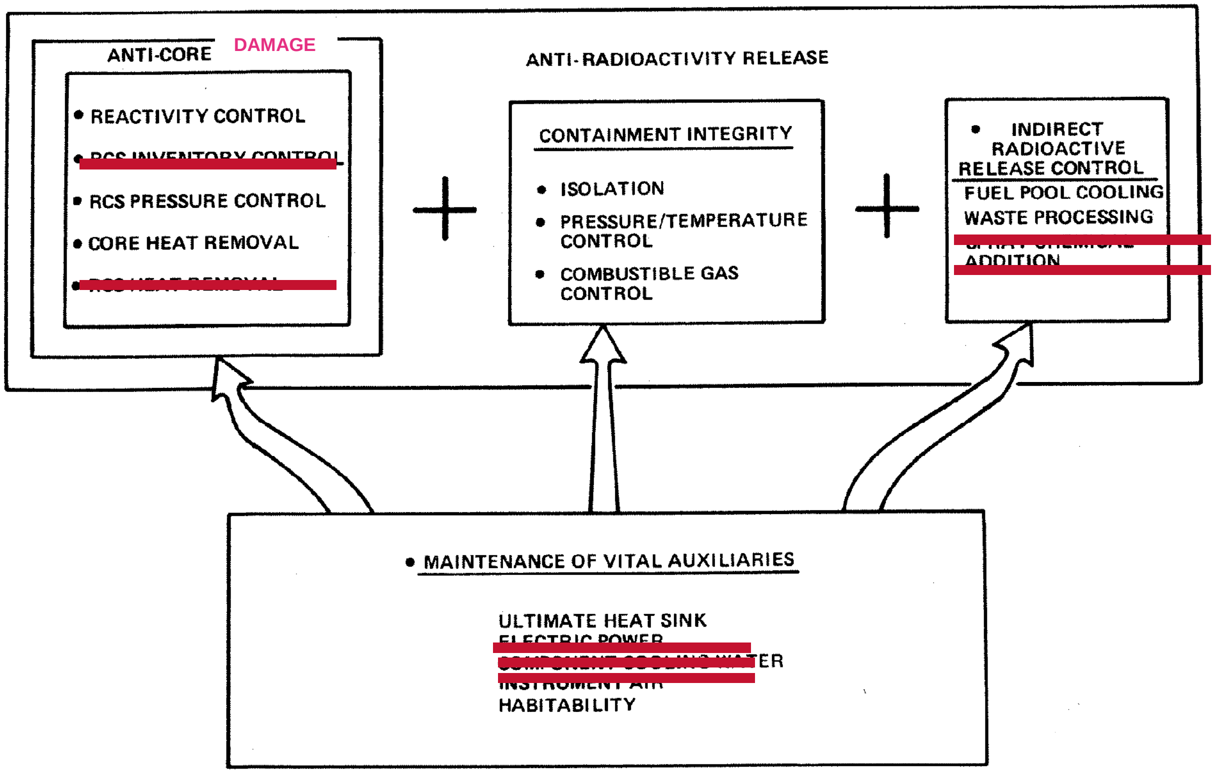

Fig. 1. Classes of safety functions.

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Safety Functionality for NPPs

- **Anticipated Operational Occurrences accommodated with high reliability**

- **Design Basis Events – Natural Phenomena (hurricanes, tornadoes, earthquakes, floods, et cetera) as well as postulated faults accidents (LOCA, MSLB, etc.) Meet PAGs at EAB. NGNP is intended to be designed to meet PAGs at 400 meters.**

- **Beyond Design Basis Events – Severe Accidents – not important how you got here, its how you manage it and isolate it. (e.g. FD1 earthquake, tsunami-both worse than design basis) FD1 survived the beyond design basis earthquake well, it appeared. It is the BDBE tsunami that stopped the safety related equipment.**

Safety Functionality for LWR v. HTGR

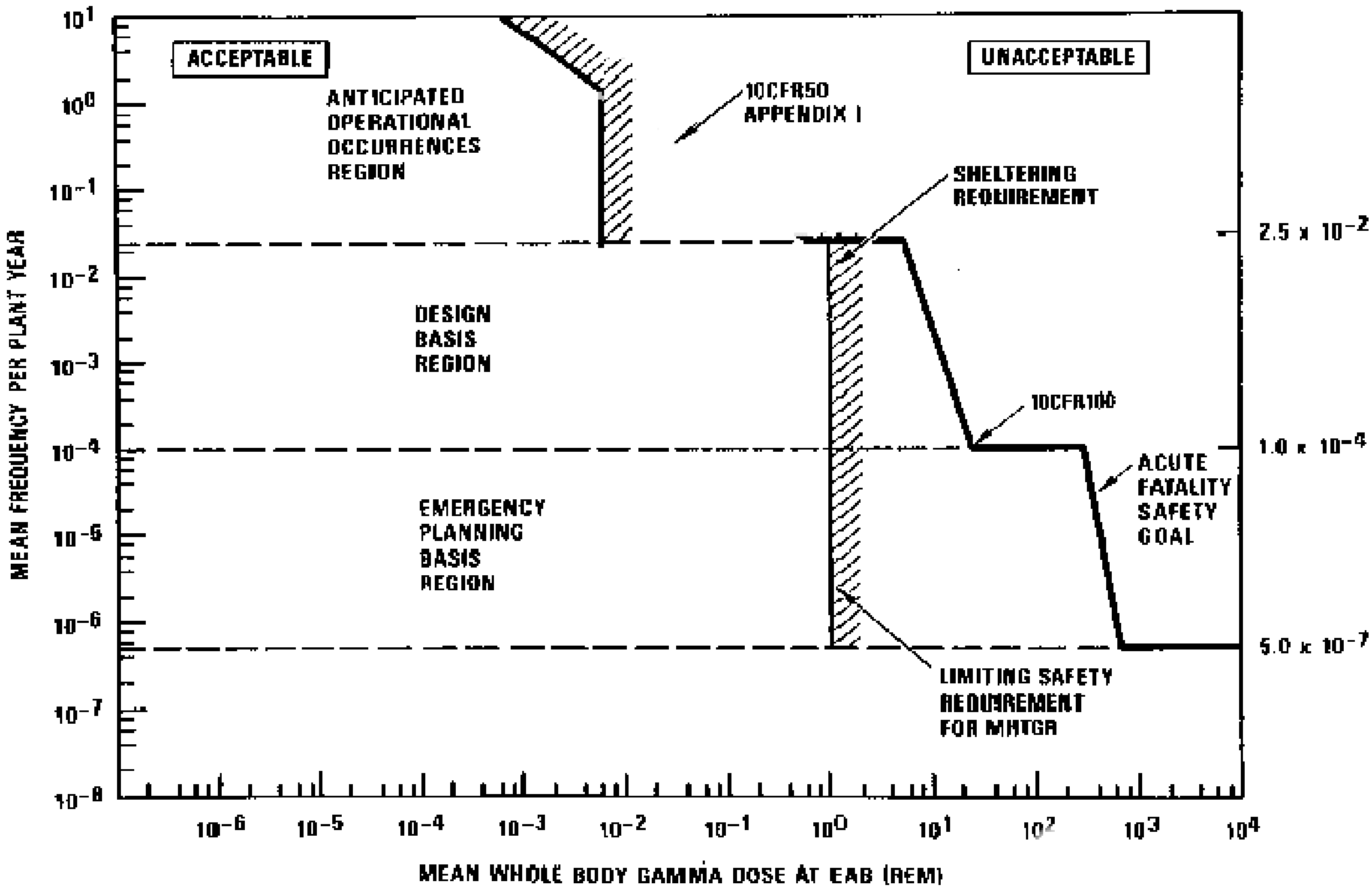
LWR BDBE management

- **must have A/C to manage the accident**
- **decay heat removal must start within about 30-40 minutes to prevent core damage**
- **maintain primary containment integrity-in severe accident vent to atmosphere or secondary containment – use hydrogen igniter or recombiner**
- **maintain spent fuel pool cooling -- could be done by a hose from a non-electric source –fire water tower, fire truck, etc. –just need to make up for boiling**

HTGR BDBE management

- **decay heat removal must start in about 100 hours**
- **heat would transfer to earth by conduction, radiation and convection (passive) for the reactor vessel.**

Applicable Frequency Ranges of Regulatory Criteria



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Fukushima Impact on New Builds

As a result of the Fukushima crisis, China has announced a hold on approvals for new projects, but this is not expected to affect projects already approved or under way.

- **Four AP1000s are under construction in China—two at Haiyang and two more at Sanmen. The first of these are to begin operation by mid-2013.**
- **Eighteen CPR-1000s, developed from a French 900-megawatt pressurized water reactor, are also being built, as well as**
- **Two AREVA EPRs, and**
- **Three indigenously designed CNP-600 units.**
- **Two HTR-PM?**

Fukushima Near-term Actions

As a result of the Fukushima crisis, Near Term NRC Reviews

- **verifying each plant's capability to manage major challenges, such as aircraft impacts and losses of large areas of the plant due to natural events, fires or explosions**
- **verifying each plant's capability to manage a total loss of off-site power**
- **verifying the capability to mitigate flooding and the impact of floods on systems inside and outside the plant**
- **performing walk-downs and inspection of important equipment needed to respond successfully to extreme events like fires and flood.**

