High Temperature Gas-cooled Reactor: Introduction

Advanced Reactor Technologies

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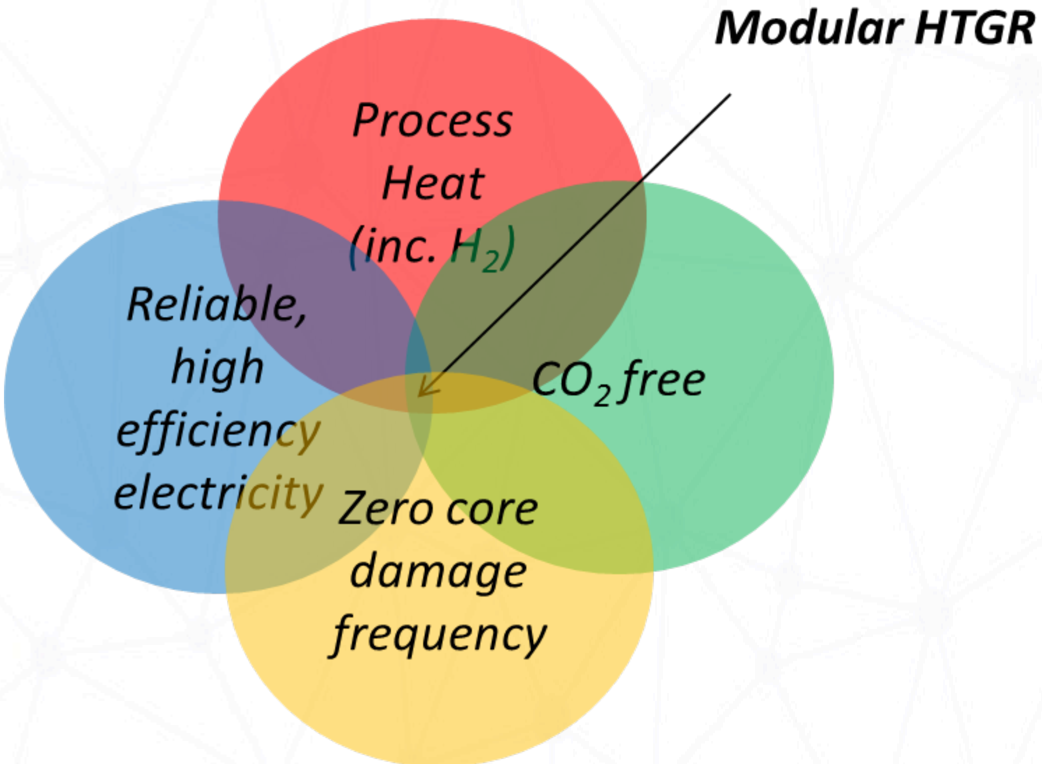
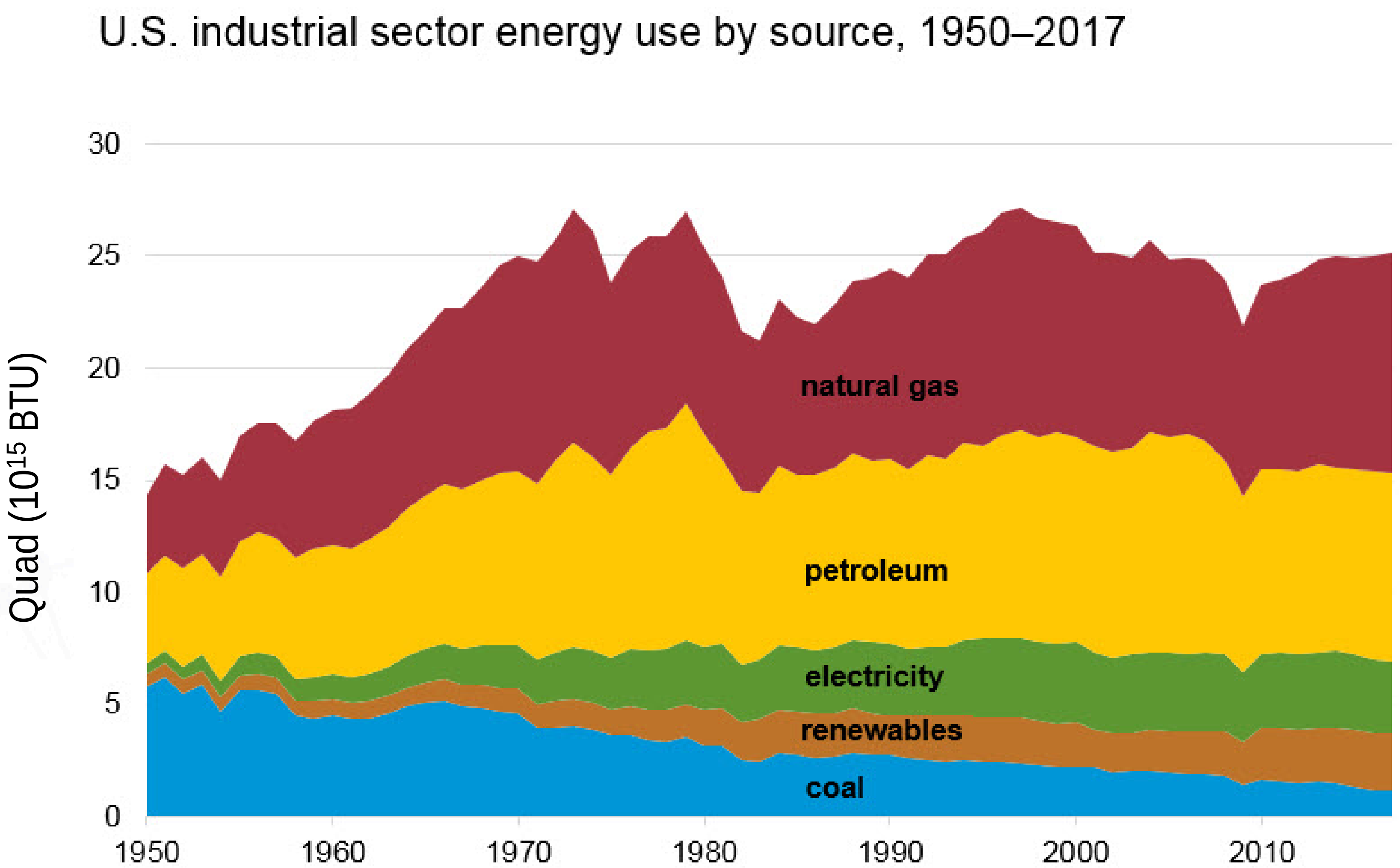
ADVANCED REACTOR TECHNOLOGIES

Modular High Temperature Gas-cooled Reactors

- Inherently safe core cannot melt
- High outlet temperature for more efficient electricity production and process heat
- Minimal radiological or dynamic coupling between the reactor and the collocated process heat application
- Environmentally benign, reliable, mature (for a non-LWR)

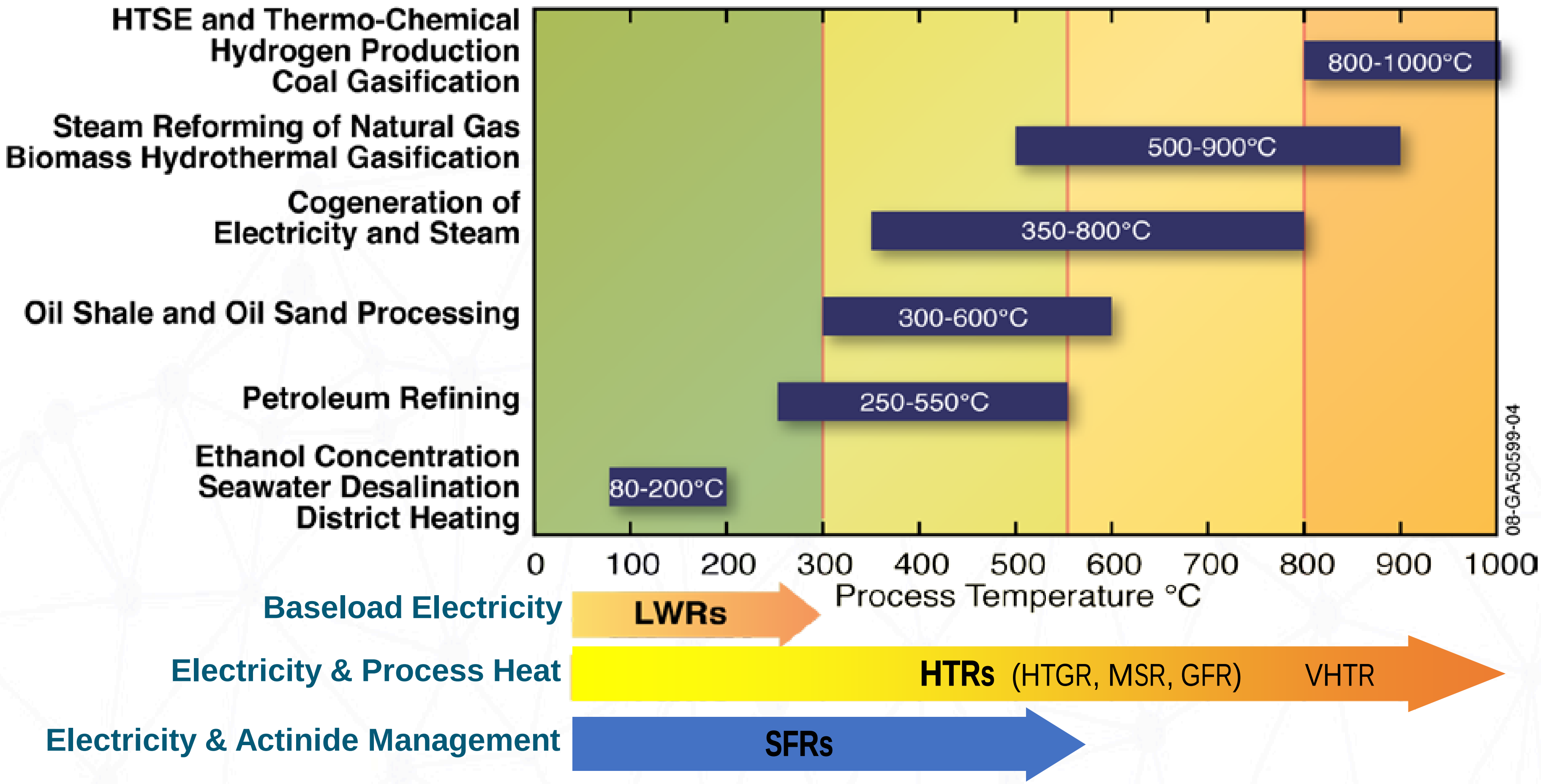


Electricity Fraction of Industrial Energy Use



Note: Includes energy sources used as feedstocks in manufacturing products. Electricity is retail purchases. Renewables are mainly biomass.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 2.4, May 2018

Some Process Heat Applications suitable for Nuclear

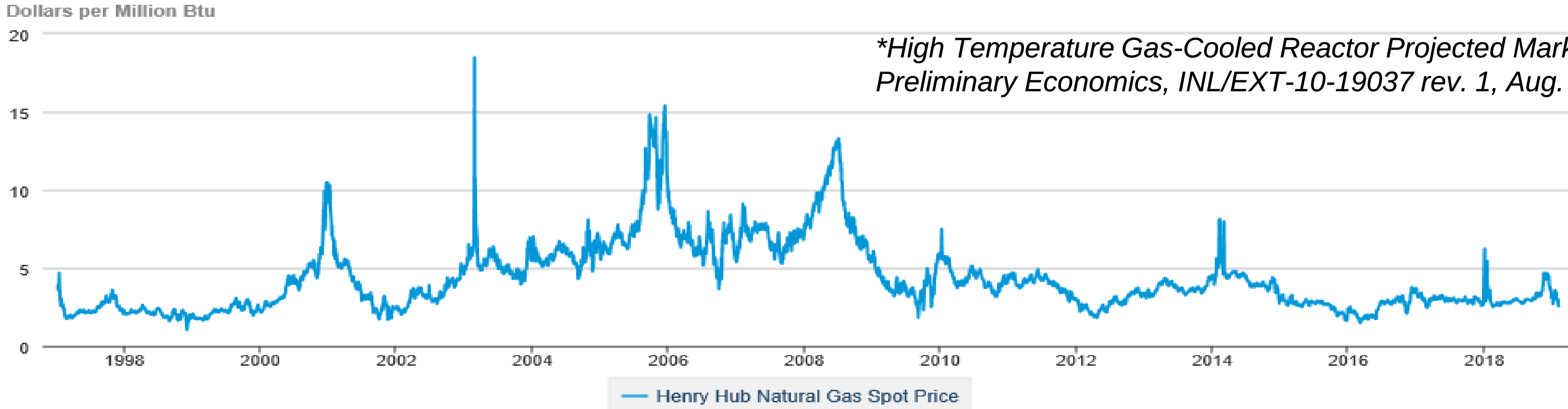


Potential Markets for Modular HTGR Steam

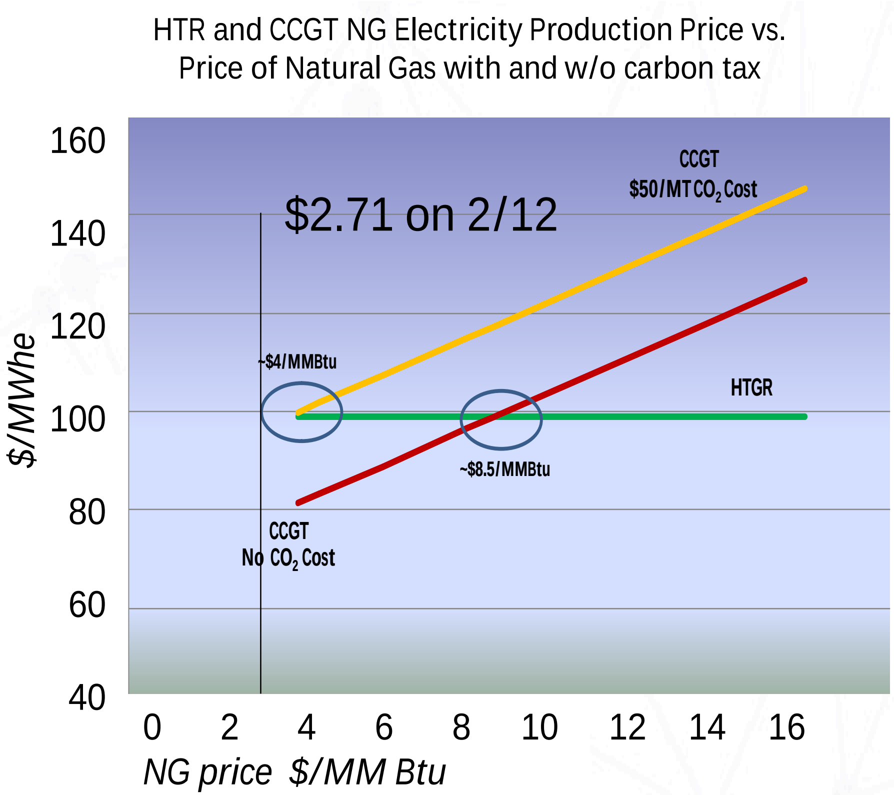
Business Subsector	Target Industry	Required heat input (MWt) between 300ºC and 850ºC	Number of 150 MWt HTGRs Required
Petroleum and Coal Products	Refineries	13456	399
Primary Metal Manufacturing	Iron and Steel mills	3225	226
Chemical Manufacturing	Basic Chemical Manufacturing (Methanol)	12714	85
	Ethyl Alcohol	3448	23
	Plastics Material and Resin	8780	60
	Alkalies and Chlorine	545	4
	Fertilizer (Ammonia)	2448	16
Food Manufacturing	Wet Corn Milling	2239	15
Mining (exc. oil & gas)	Potash, Soda, Borate	3318	22

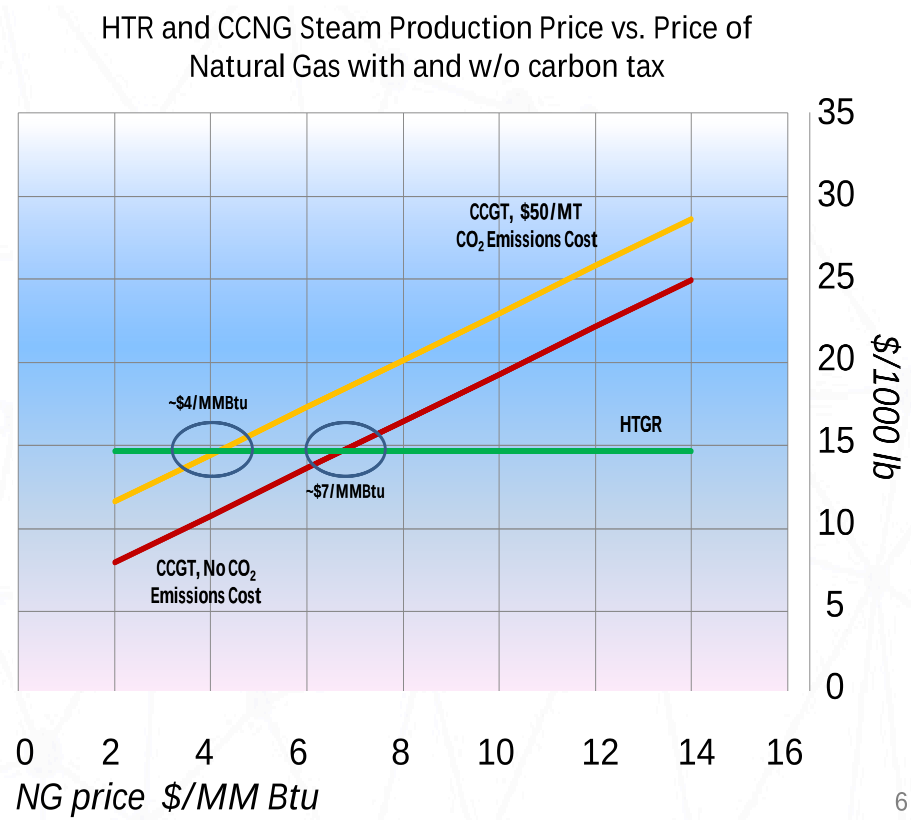
McMillan, C. et al, "Generation and Use of Thermal Energy in the U.S. Industrial Sector and Opportunities to Reduce its Carbon Emissions", NREL/TP-6A50-66763, INL/EXT-16-39680

Cost of Energy – HTGR vs. Natural Gas



**High Temperature Gas-Cooled Reactor Projected Markets and Preliminary Economics, INL/EXT-10-19037 rev. 1, Aug. 2011.*





Relatively Mature Technology

Proof of Performance

FORT ST. VRAIN – 842 MWt
(U.S.A.)
1976 - 1989

THTR – 750 MWt
(FRG)
1986 - 1989

…but the fuels, materials, and methods must be qualified for today's market and regulatory environment

Engineering Reactors

HTTR – 30 MWt
(Japan)
1999 - present

HTR-10 – 10 MWt
(China)
2000 - present

DRAGON – 20 MWt
(U.K.)
1964 – 1975

AVR – 46 MWt
(FRG)
1967 - 1988

PEACH BOTTOM 1 – 115 MWt
(U.S.A.)
1967 - 1974

Current Industrial Interest in TRISO-fueled power

Larger (200-625MWt) Plants for the Grid and Heat Users

Kairos Power

framatome

X energy

Microreactors (5-50 MWt) Units for Off-grid, Military Power

GENERAL ATOMICS

STARCORE NUCLEAR

BWXT
BWX Technologies, Inc.

HolosGen™

U BATTERY
Local Modular Energy

US ULTRA SAFE NUCLEAR

High Level Safety Design Objectives

- Meet regulatory dose limits at the Exclusion Area Boundary (EAB)
  - 25 rem Total Effective Dose Equivalent (TEDE) for duration of the release from 10 CFR 50.34 (10 CFR 52.79) at EAB for design basis accidents
  - EAB is typically estimated to be approximately 400 meters from the plant for a modular HTGR; supports co-location with industrial facilities
- Meet safety goals for cumulative individual risk for normal and off-normal operation
- Meet the EPA Protective Action Guides (PAGs) at the EAB as a design goal
  - 1 rem TEDE for sheltering
  - Design basis and beyond design basis events are considered
  - Realistically evaluated at the EAB
  - Emergency planning and protection

High Level Safety Design Approach

- Design using materials with properties that retain integrity at high temperature and are chemically stable
  - Helium coolant – neutronically transparent, chemically inert, low heat capacity, single phase
  - Ceramic coated fuel – high temperature capability, high radionuclide retention
  - Graphite moderator – high temperature stability, large heat capacity, long thermal response times
- Design the reactor with inherent and passive safety features
  - Retain radionuclides at their source within the fuel
  - Shape and size of the reactor allows for passive core heat removal from the reactor core through the uninsulated reactor vessel
    - Heat is still removed if the system is depressurized as a result of a breach in the reactor helium pressure boundary
    - Heat is radiated from the reactor vessel to the reactor cavity cooling system (RCCS) panels and rejected passively to the environment
  - Large negative temperature coefficient for intrinsic reactor shutdown
  - No reliance on AC-power to perform necessary safety functions
  - No reliance on operator action and insensitive to incorrect operator actions

Modular HTGR Safety Basis and Approach paper submitted for information to NRC, INL/EXT-11-22708, September 2011, ML14174A774

Comments to Address Issues from NRC Review

- Training slides are organized according to previously agreed-upon agenda topics and are consistent with previous training courses; therefore, not reorganized around specific learning objectives
- NRC ML numbers have been provided in the Suggested Reading lists where they apply

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