Hyperion

Power Generation

NRC Pre-application Meeting

22 August 2007

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Agenda

- **Introduction**
- **Applications**
- **Technical Overview**
- **Design & Testing**
- **NRC Licensing & Commercialization**

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Introduction

John R. Grizz Deal
CEO
Hyperion Power Generation, Inc.

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Hyperion Team

- **Purple Mountain Ventures (PMV)**
  - **Commercialization & Management**
- **Altira Group**
  - **Capital**
- **Los Alamos National Laboratory (LANL)**
  - **Technology**

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HPG, Inc. Team

- **John R. (Grizz) Deal**
  - **CEO HPG, Inc., & PMV Managing Director**
- **Deborah A. Blackwell**
  - **VP HPG, Inc. & Program Manager, PMV Director**
- **L. Robert (Bob) Libutti**
  - **VP HPG, Inc. & PMV Director**
- **Otis (Pete) Peterson**
  - **Hyperion Inventor (LANL Retired)**

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Motivation

Why are we here?

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PMV Motivation

- **Purple Mountain Credo**
  - **Invest our time and money into projects that have a significant positive impact**
  - **Focus on "bleeding" edge, emerging technologies that ordinarily wouldn't see the light of day**
  - **Acquire that difficult-to-establish first market segment/first customer**

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LANL & Altira Motivation

- **LANL**
  - **See taxpayer-funded technologies reach broadest market**
  - **Make positive impact on U.S. economy**
- **Altira**
  - **Generate wealth form alternative energy industries**

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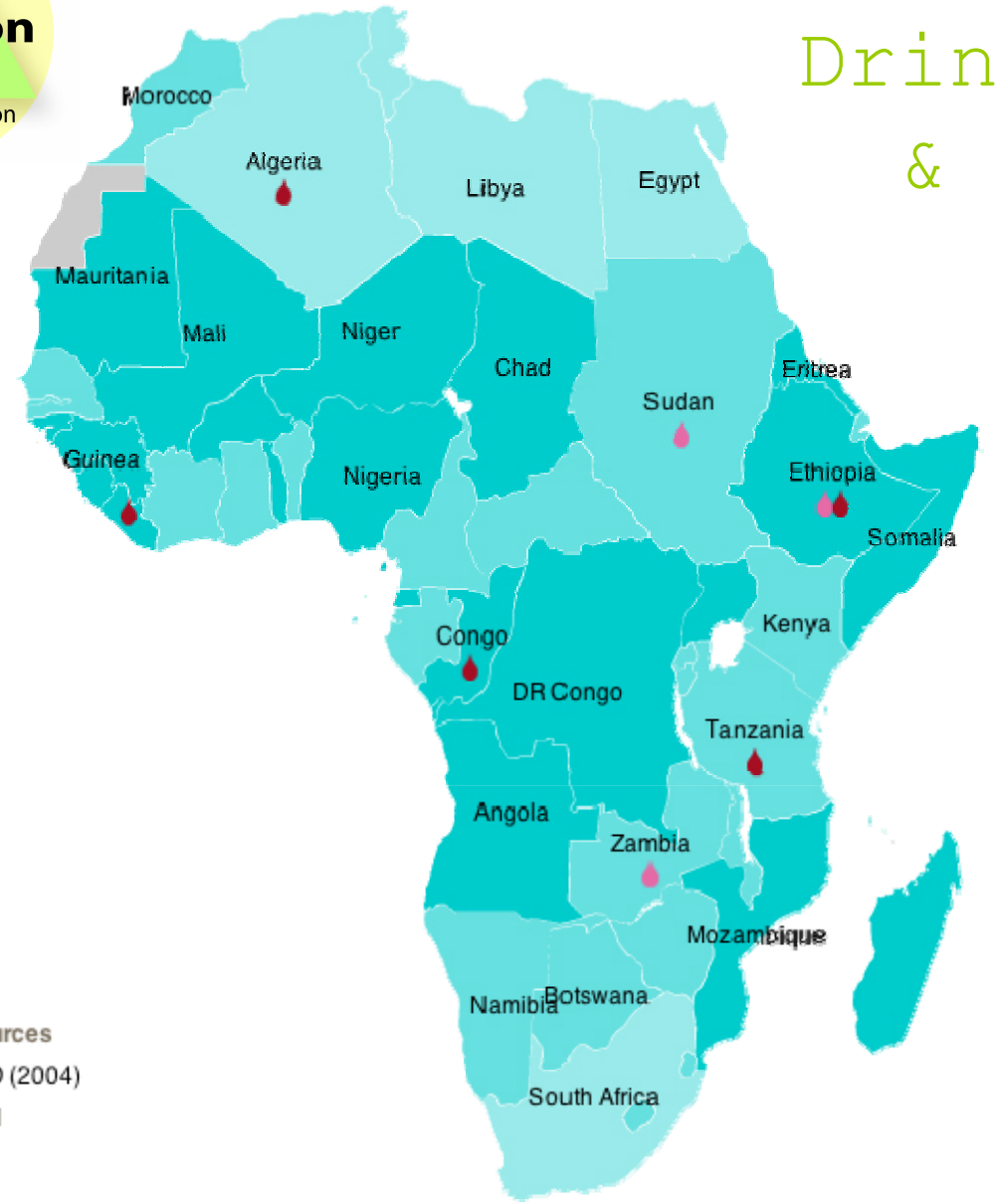
PMV Motivation
Drinking Water & Sanitation



Access to water and sanitation

- Extreme risk (under 50%)
- High risk (50% - 75%)
- Medium risk (75% - 90%)
- Low risk (over 90%)
- No data

Icons

- Flashpoints
- Hotspots

Key data sources

UNICEF/WHO (2004)

Last updated

January 2007

Courtesy DATA.org

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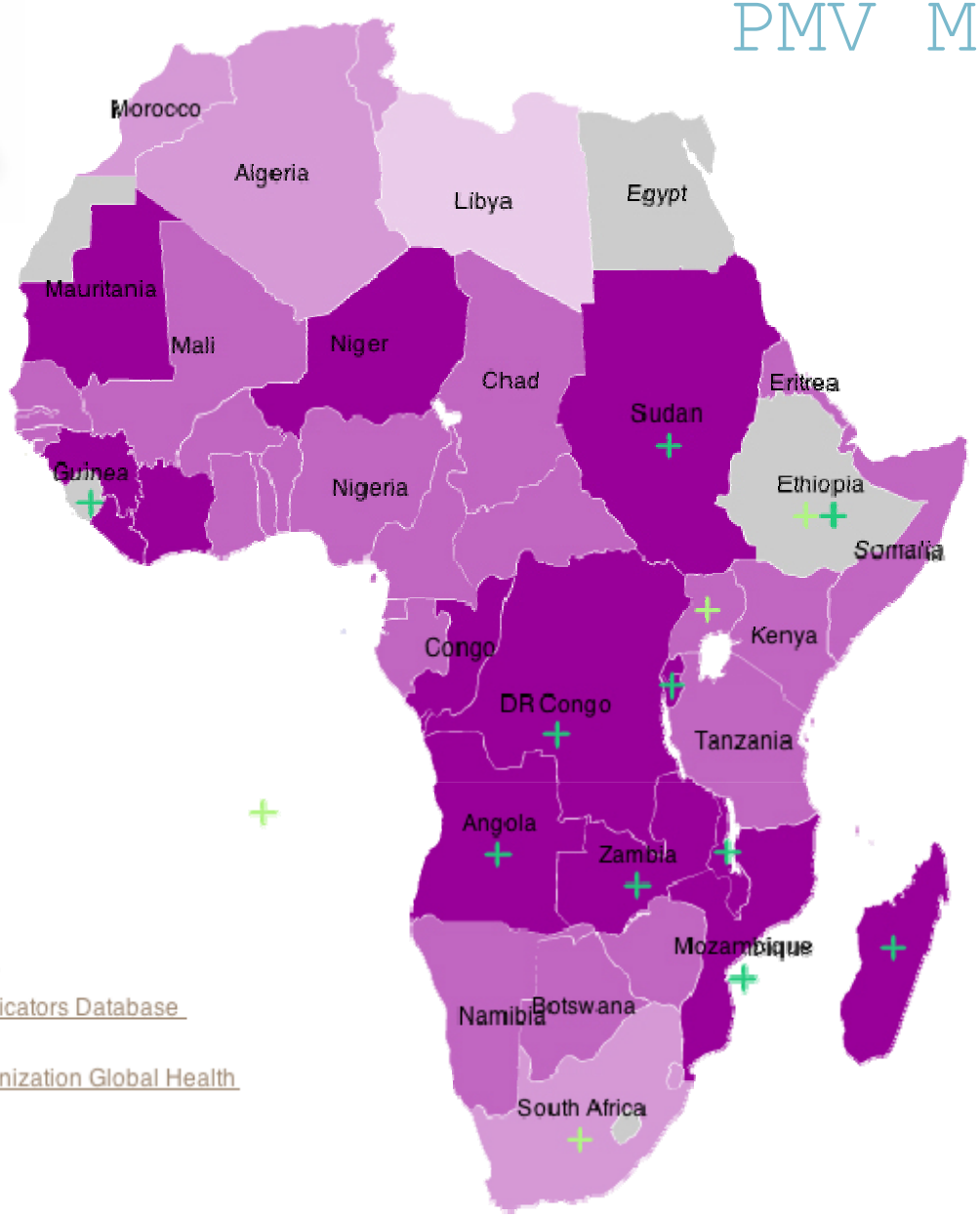
PMV Motivation
Malaria



Malaria Index (MI)
- Extreme (0-2.5)
- High (2.5-5.0)
- Medium (5.0-7.5)
- Low (7.5-10)
- No reported cases
- No data

Icons
- Flashpoints
- Hotspots

Key data sources

UN Millennium Indicators Database (2004)

World Health Organization Global Health Atlas (2002)

Last updated
January 2007

Courtesy DATA.org

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PMV Motivation
Power for Remote Communities

- **Enormous power disparity between developed and developing regions**
- **Disparity exists even between mainland U.S. and its "off-shore" protectorates**
- **Healthcare, economic growth, food supply…all impacted by this power disparity**

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PMV Motivation
Efficient Hydrocarbon Recovery

- **Oil sands & shales**
  - **Up to 35% of energy recovered is lost in recovery itself**
  - **Inefficiencies create additional greenhouse gases, waste, and have a destabilizing impact on prices**

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Applications

Deborah A. Blackwell

VP HPG, Inc.

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Hyperion: a New paradigm for Nuclear Power

- **Small reactors instead of giants**
  - **Distributed production (wave of future)**
- **Self regulating**
  - **Inherently safe**
  - **No mechanical moving parts**
- **Bury underground**
  - **Safe from threats**
  - **Radiation shielded**
  - **Out of sight**
- **Economy of mass production instead of economy of scale**
- **Standardization of design reduces certification to a single event**

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…Hyperion continued

- **25 MW of electrical power each (25,000 homes)**
- **Sealed modules**
  - **Factory refueling greatly hampers proliferation attempts**
- **Replace oxide fuel and aqueous reprocessing**
  - **Minimizing instead of expanding waste**
  - **Recycle actinides**
- **Use all fissile & fertile elements: U, Pu & Th**
- **Reduces investment risk**
- **Reduces time to market**

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The Economics of Hydride Reactors is Very Attractive

- **Capital costs (estimates provided by a member of the nuclear industry):**
  - **Thermal power: 68 MW_{th} for $20,000,000**
  - **Electrical power: 27 MW_e for $37,000,000 ($1380/kW_e)**
    - **Conventional plants estimated $2000/$kW_e$ (MIT study)**
- **Operating fuel costs:**
  - **Fuel for 5 years of operation: $12.7 million**
- **Small size and cost minimizes financial risk**
- **5 year investment for steam generation:**
  - **Hydride nuclear: $3/M BTU - $33 million per unit**
    - **Natural gas comparison costs: $7-$14 per M BTU.**
  - **5 year savings for heavy oil field: approx.** $2 billion

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Hyperion is Needed

- **By remote communities**
- **To access unconventional hydrocarbons**
- **To meet the growing energy problem**

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The Energy Problem

- **Global energy demand increased 60% in last 25 years**
- **Forecasts for the next 25 years project same**
  - **rapid development in China & other developing countries**
- **National Petroleum Council* recognizes that ALL types of energy sources are needed**
  - **not just oil and gas**
  - **includes nuclear, solar, wind**
- **International Energy Association's 2006 World Energy Outlook – predicts massive new investments in large scale projects will be required to develop and deliver energy**
  - **$20 trillion will be required over the next 25 years;**
  - **$3,000 per person alive today**

* *National Petroleum Council, Draft Report – "Facing the Hard Truths about Energy" July 18, 2007*

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The Water Problem

Basic Human Rights and Survival affected by the Energy-Water Nexus

- ***Remote, independent (off the grid) power and water is needed**
  - **hospitals, schools, sanitation, irrigation, industry, drinking, cooking**
- **Technologies and abilities sufficient to ensure food supply**
  - **~ 13% of the world's population does not have access to enough food and water to live a healthy and productive life**
  - **could produce enough food for every man, woman and child in the world do currently exist.**
- **Poverty is driven by**
  - **lack of health, financial, & natural resources**
  - **lack of skills to link productive activities with remote markets and ensure employment**

*United Nations

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The Water Problem

Basic Human Rights and Survival affected by the Energy-Water Nexus

- **An accessible supply of clean water is essential to improving health, education and overall productivity around the world**
- **Population growth and economic expansion**
  - **placing huge demands on coastal and freshwater ecosystems**
  - **water withdrawals have increased 6X since the 1900s**
    - **twice the rate of population growth**
- **Over one billion people lack access to a basic supply of clean water**
  - **~25% (311 million) in sub-Saharan Africa**
  - **~45% of Africa's population lacks access to clean water**

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Access to Clean Water is Essential

- **Water related illnesses affect more people on earth than any other disease**
- **Sanitation coverage in developing countries (49%) is only half that of the developed world (98%)**
- **Unsafe water and poor sanitation**
  - **cause intestinal worms, cholera, & diarrhea**
    - **diarrhea is the 3rd biggest child killer in Africa (after pneumonia and malaria)**
    - **kills over 700,000 children a year**
- **A baby born in Africa is over 500 times more likely to die from diarrhea than a baby born in a G8 country**
- **A child dies every 15 seconds from water-related diseases**
  - **+5,700 deaths a day**
- **Improving water and sanitation would save $ millions in patient treatment cost**

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Hyperion is the Solution to the Clean Water Problem

- **No CO_2 emissions**
  - **clean power is needed as global warming will only increase human misery**
- **Tamper resistant**
  - **nonproliferation**
- **Effective cost-ratio**
- **No human interface with its chemistry**
- **Portable**
  - **Ideal for remote locations**

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Hyperion Economically Assists in Heavy Oil Extraction

- **Heavy hydrocarbons (oil, shale, sands, etc.) require heat to liberate.**
- **Single oil field can consume over 1000 megawatts of thermal power.**
- **If powered by natural gas, consumption is over 100 million cubic feet per day.**
- **Costs of natural gas range from $0.5 to 1.5 million per day depending on gas price.**
- **Nuclear power costs approx. $250k per day.**
- **<u>Cost savings for 5 year life of power sources is between $1 and 2 billion</u>.**

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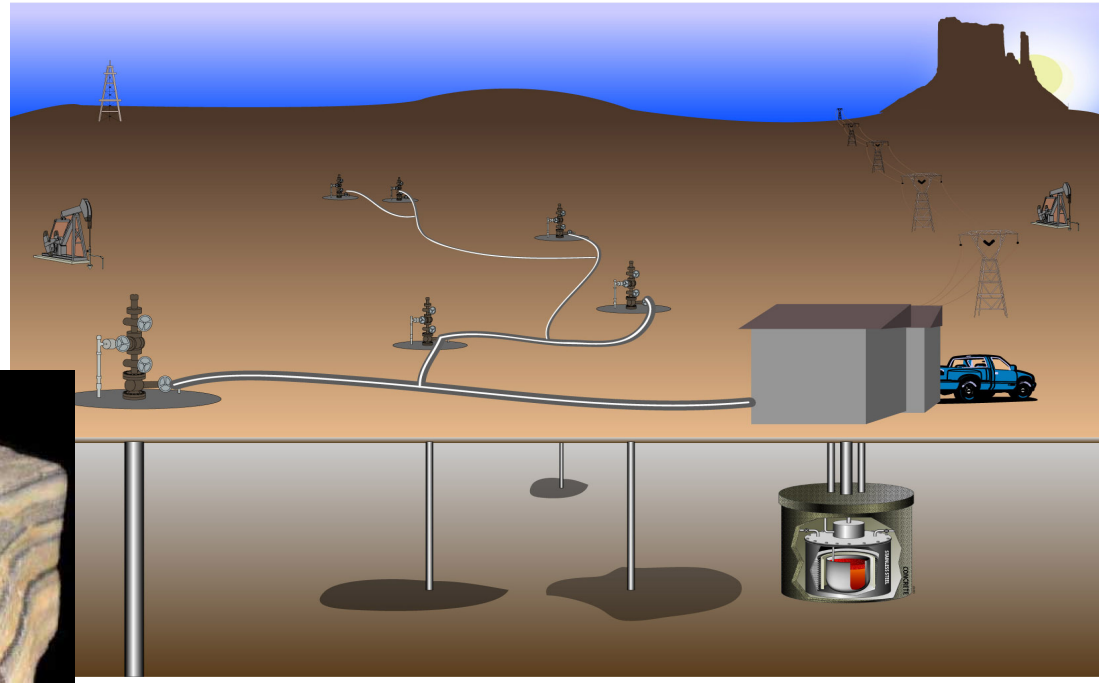
Hyperion Will Dramatically Reduce the Cost of Recovering Oil from Shale & Sand



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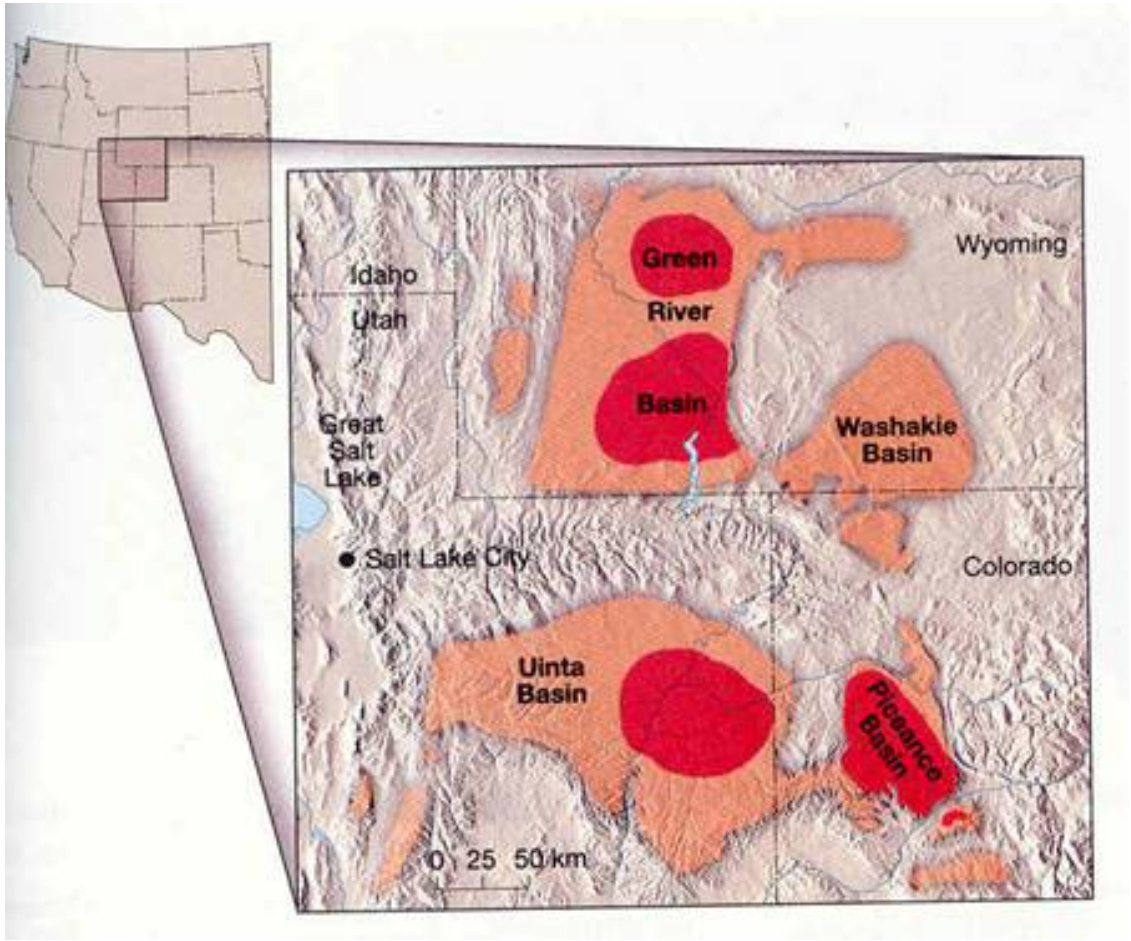
The Western U.S. has Trillions of Barrels of Oil Trapped in Shales & Sands



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Technical Overview

Otis (Pete) Peterson

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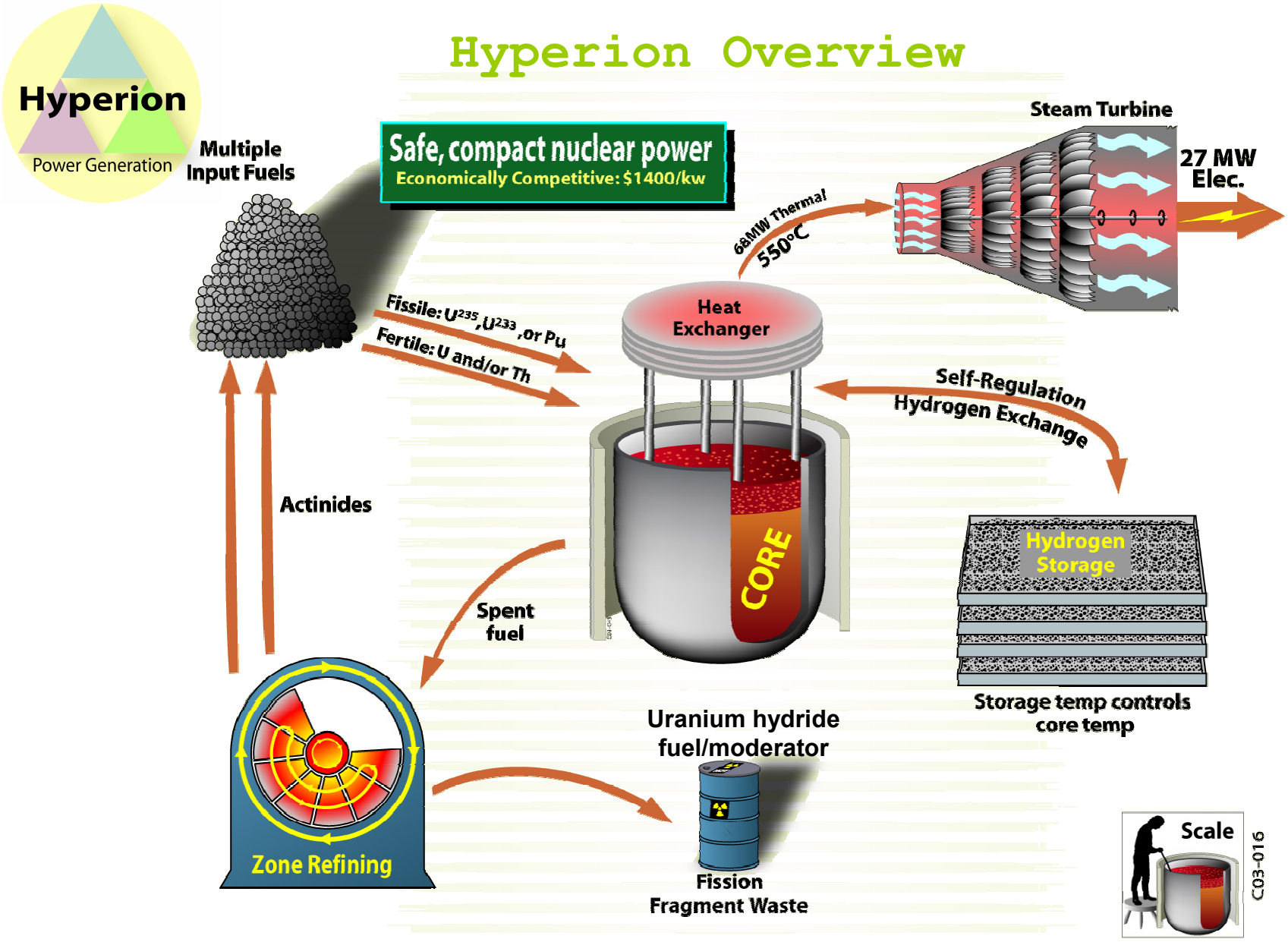
Hyperion Overview



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Hydride reactor safely stored underground in sealed vault

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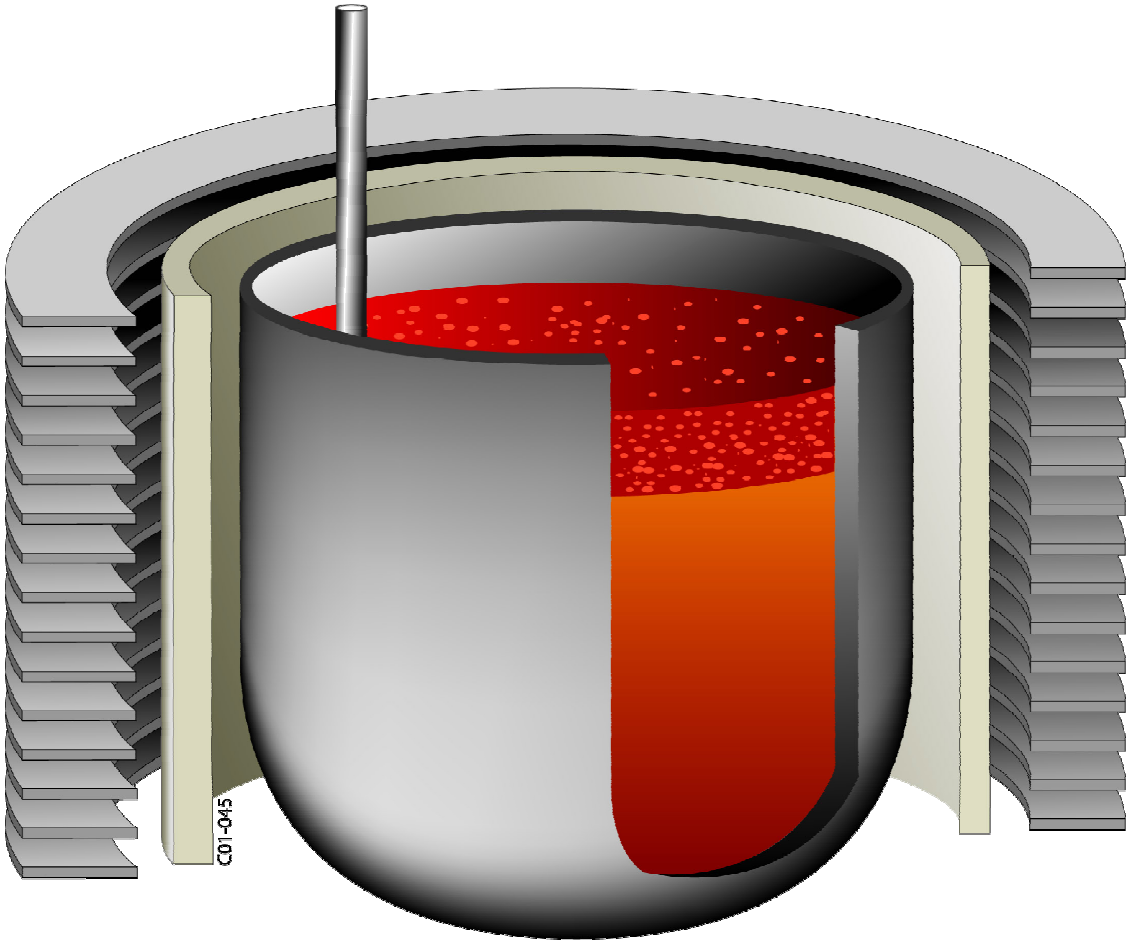
Hydride Reactor Size



1/2 m

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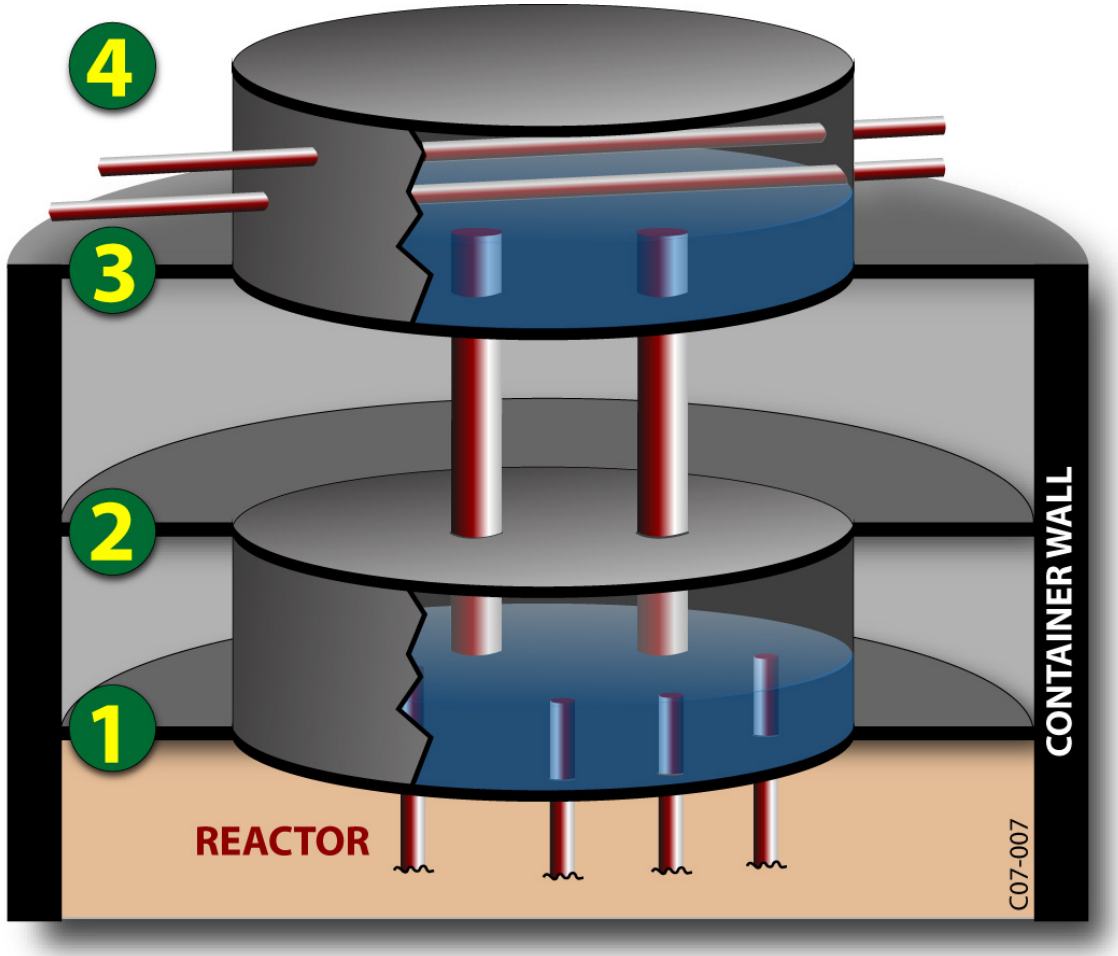
Heat Extraction Includes Multiple Containment



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Hyperion Breaks the Paradigm

Characteristic	IRIS	PBMR	4S	ENHS	Hyperion
Fuel	UO_2	UO_2/U_2C_3	U	U	**UH_3**
Coolant	H_2O	He	Na	Pb-Bi	**K**
Volume (m^3)	760	1500	110	160	**10**
Power (MW_e/MW_{th})	100/300	100/260	50/120	50/120	**30/75**
Factory fueled	No	No	No	Yes	**Yes**
Safety + control elements	40	24	7	7	**zero**
Internal pumps	6	2	1	zero	**zero**

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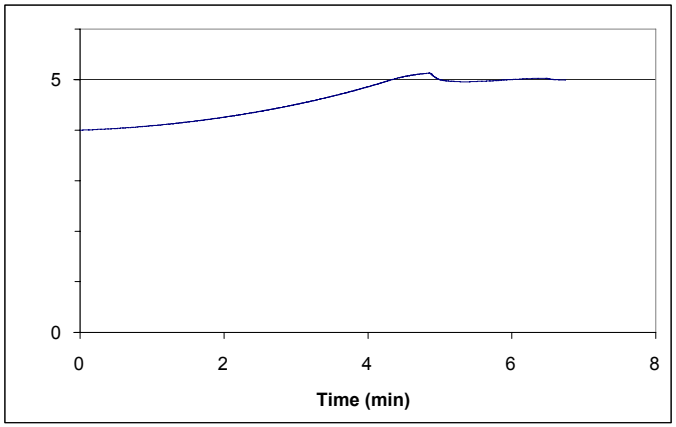
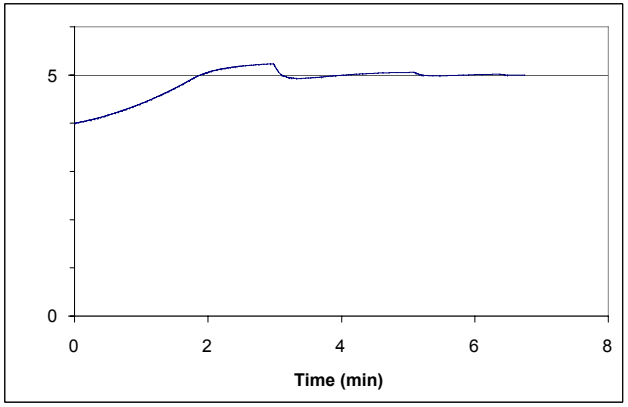
The Hyperion Reactor Is Stable

- **Transients damp out in a few minutes**
- **Rapid changes in power generate transients**
  - **5°C/min.: top figure**
  - **50°C/min.: bottom figure**
- **Order of magnitude rate changes do not affect stability101**





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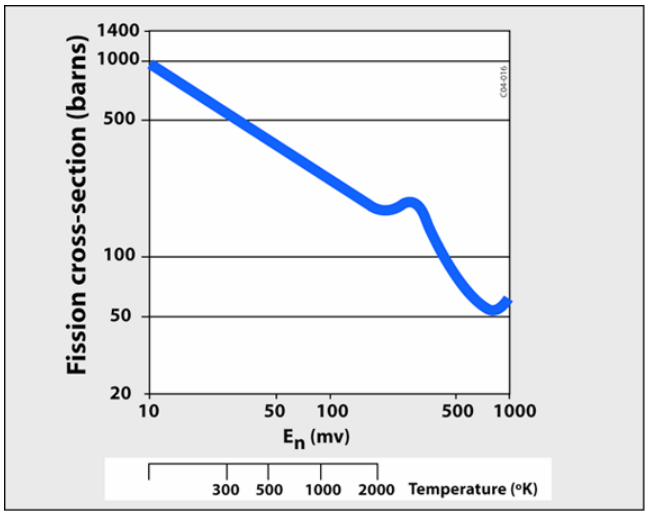
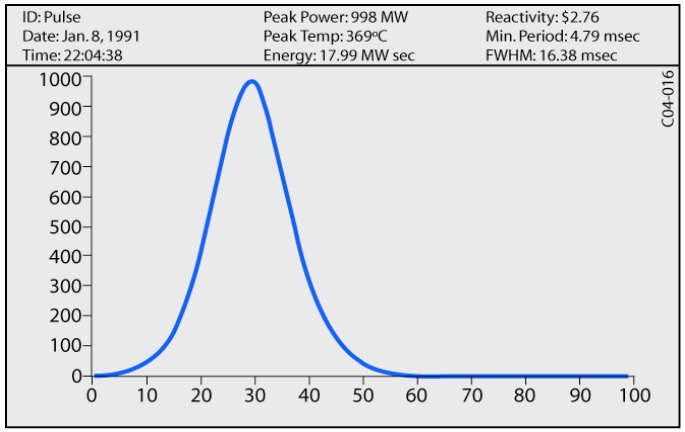
Hydride Fuels Have a Half Century of Demonstrated Safety

- **Hydride fuels are safe from temperature over-excursions**
  - **Common fuel/moderator yields warm neutrons**
  - **Fission cross-sections decrease as 1/velocity**
  - **Safe above prompt critical**
  - **Self-terminated pulses from 1 MW to 20 GW in 10 to 20 ms**
  - **Temperature rise up to 200°C**
- **Safety demonstrated at over 60 installations**
  - **Safety proven by TRIGA and SNAP reactors**
  - **TRIGA certified for unattended operation**





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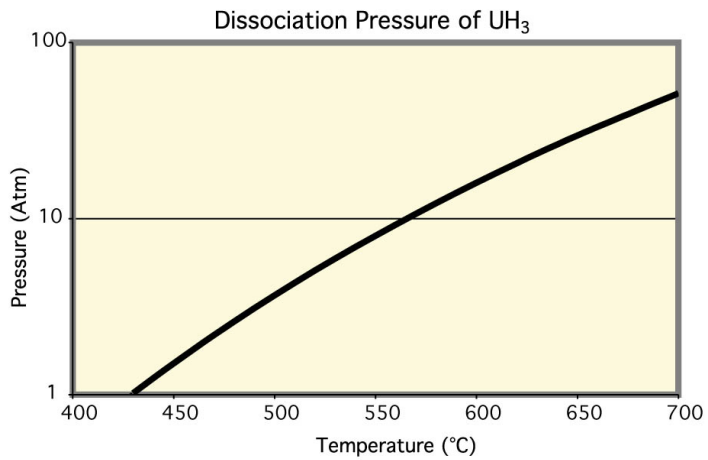
Uranium Hydride Was Created for Nuclear Reactor Applications

- Hydrogen is most effective moderator
- High storage density for hydrogen moderator: comparable to water and liquid hydrogen
- High dissociation pressure (8 atm) at high temperature (550ºC)
  - Enhances gas and thermal transport
  - Improves power conversion (40%) using supercritical water (superheated steam)
- UH_3 inherently forms as a powder
  - Particle size is very small (<75 microns)
  - Does not fuse under 900ºC
  - Enhances diffusion escape rate (<30 ms)
- High mobility of hydrogen enhances difusion and gas flow



Core Property	Bare Core	Half Heat Pipes
U^{235} enrichment	4.94%	5 %
Final enrichment	4.94%	3.5%
UH_3 powder density	7.5 g/cm^3	7.5 g/cm^3
Void fraction	0.32	0.32
U^{235} critical mass	30 kg	440 kg
Total critical mass	0.61 MT	8.8 MT
Critical volume	83 liters	2400 liters
Critical diameter	0.54 m	1.44 m
Energy content	Zero	340 MW yrs
Electrical power	Zero	27 MW
Number of heat pipes	Zero	1600

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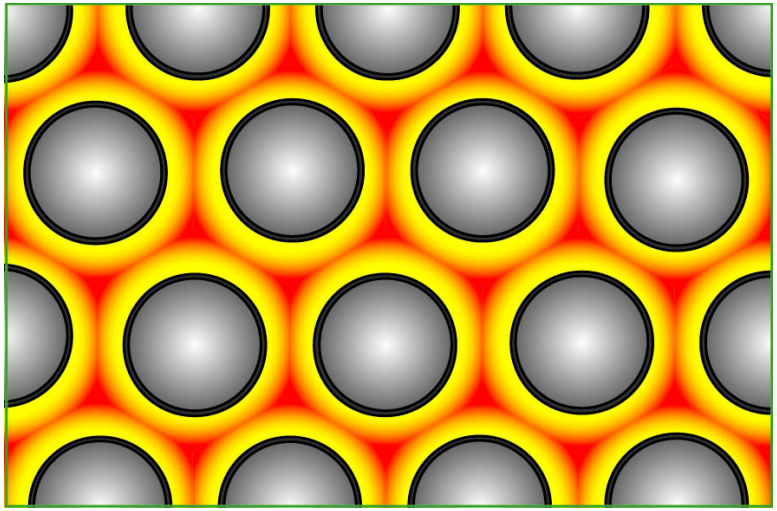
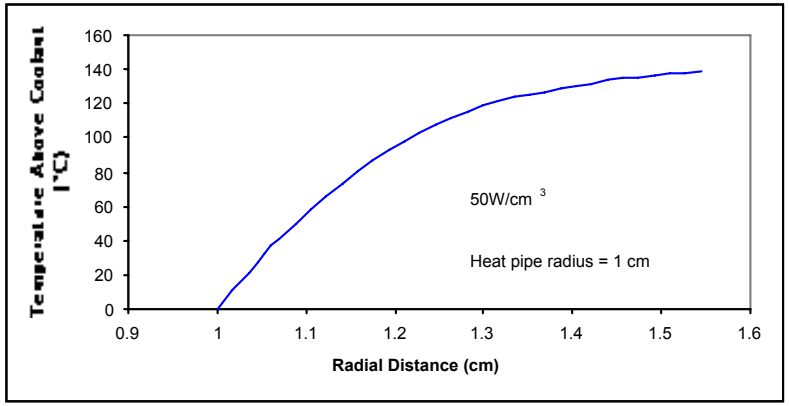
Practical Deployment Requires Power Extraction

- **Coolant must be non-moderating:**
  - **Potassium heat pipes**
- **Reserve half of volume for cooling**
  - **1600 heat pipes (1 inch) in 1.4 m OD core**
  - **Pipe diameter = 3/4 of spacing**
- **Temperature gradient extracts power**
  - **Five year operation permits 50 W/cm^3**
  - **Powdered fuel has low conductivity: 0.04 W/cm/°C**
- **Effective temperature is above coolant**
  - **Mass averaged $\Delta T = 90$ °C**
  - **H_2 reservoir temperature equals highest of fuel -- safer operation**





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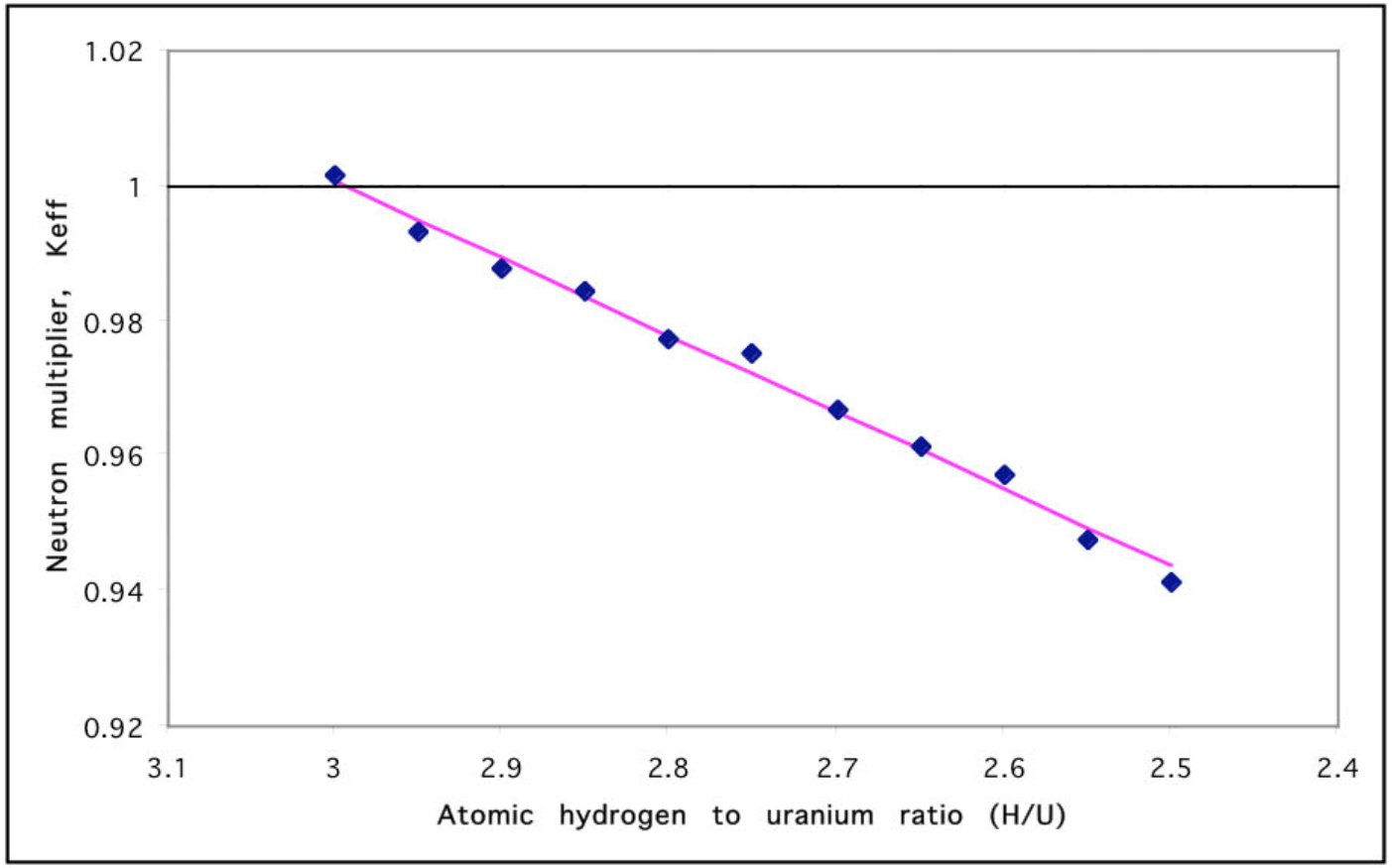
Moderator Depletion Reduces Neutron Multiplication



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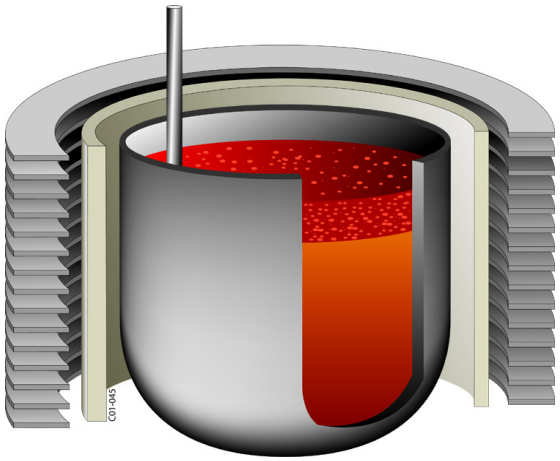
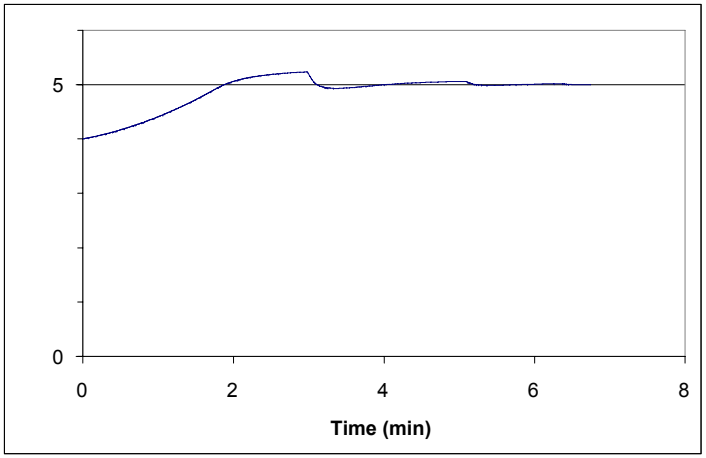
Compact, Self-Stabilizing Nuclear Power Source

- Based on uranium hydride
  - **Both fuel & moderator**
  - **Hydrogen volatility stabilizes reactor**
  - **Power transients damped by H transport**
- Change power production paradigm
  - **Many dispersed & redundant sources**
  - **Source sited and controlled locally**
- Economically competitive ($1400/kw) from inherent safety and stability
  - **Power transients damped out**
  - **Mass produced**
  - **No mechanical moving parts**
  - **Minimum human oversight**
  - **High (550ºC) operating temperature**
  - **Constant temperature: load following**
- Minimize investment risk
  - **Compact 1 to 2 m diameter core**
  - **Multi-10s of megawatt production**
  - **Multi-year use from factory sealed unit**
- Spent fuel easily processed
  - **Zone refining separations**
  - **Only power added to spent fuel**





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Design & Testing

Otis (Pete) Peterson

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Hyperion Testing

- **Gas Flow Dynamics Modeling**
- **Experimental Demonstration**
- **Material Capability**

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NRC Licensing & Commercialization

Deborah A. Blackwell

VP HPG, Inc.

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Draft License Schedule

- **Now – Summer 2009: Validation**
- **October 2009: Turn over documentation of tests to NRC for pre-application review**
- **October 2011: Pre-app review completed, application for manufacturing license completed and submitted**
- **March 2015: Manufacturing license issued**
- **March 2016: Hyperion online**
  - **Assuming User/Operator has requested ESP or COL**

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