HYPERION
Power Generation

Nuclear Small Modular Reactor Energy Technology

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Caveat Lector

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Outcomes and Overview

- **"Big Nuc™" overview**
  - **Waste, Fuel Cycle, Economics**
  - **Public Perception Issues**
- **Distributed Power**
- **Small Modular Reactors (SMRs)**
  - **SMR Examples**
  - **Licensing, Economics, Operating**
  - **Safety & Security**
  - **Applications**
- **SMRs vs. other Clean Energy**

Outcomes and Overview

1. **Distinguish the difference between small modular reactor technology and other earlier nuclear technologies**
2. **Describe the unique aspects of small modular reactor technology**
3. **Discuss the challenges to small modular reactor technology, timeline, etc.**
4. **Identify the system characteristics of small modular reactor technology**
5. **List five distinct advantages obtained through production and implementation of these generation systems**
6. **Compare the advantages of small modular reactor technology to existing nuclear systems**
7. **Recognize the importance of the small modular reactor technologies and their future applications**

Key Nuclear Power Attributes

- **Baseload**
- **Cheaper than other clean power sources**
- **Emits no CO2**
- **Tightly regulated**
- **Can account for every gram of waste and emissions produced…**

Waste

- **Political issue, not a technical nor science issue**
  - **Spent fuel stored on-site for decades without incident**
  - **Office of Civilian Radioactive Waste Management (DOE) took control of civilian nuclear waste in 1982**
  - **Lack of action by Feds doesn't seem to bother industry**
    - **Waste is secure**
    - **Industry collects fees to store waste**
- **Nuclear related waste is only 1% of industrial toxic waste**
  - **Most toxic waste doesn't have a half-life**
    - **It's deadly forever**
  - **Coal plants produce 10x amount of radiation than a nuclear plant**
- **Reprocessing is key to minimizing waste**

Refueling

- **Burn-up depends on amount of U-235**
  - **Only a small percent of fuel is used**
- **Most civilian reactors are re-fueled in the field and require shutdown**
  - **Neither PBMR nor CANDU require shut-down**
- **Some SMRs are factory fueled**

Plant Economics

- **2007 U.S. electric consumption**
  - **4,157 million MWh**
- **U.S. has 104 civilian nuclear power plants @ 64 sites; 34 civilian research reactors**
  - **Produce ~18% of total electricity**
  - **Have relatively long lives**
  - **Cost is <2¢ kWh**
- **New Plants will be more expensive**
  - **$6-$9 billion per plant**
  - **Most of this is due to enormous size and materials required**
  - **Multi-gW coal plant could cost similar amount**

Public Policy

- **What went wrong**
  - **Two incidents: TMI & Chernobyl**
    - **TMI is a success story**
    - **Chernobyl design is only in FSU**
- **Emotions vs. Facts**
  - **Unfamiliar, Media hype**
- **Environmental Lobby went Pro**
  - **“When the going gets weird, the weird turn pro” – Hunter S. Thompson**

Ten Myths About Nuclear Power

1) Uranium is running out
2) Nuclear is not a low-carbon option
3) Nuclear power is expensive
4) Reactors produce too much waste
5) Decommissioning is too expensive
6) Building reactors takes too long
7) Cancer rates are higher near reactors
8) Reactors lead to weapons proliferation
9) Wind and wave power are more sustainable
10) Reactors are a terrorist target

The annual average dose per person from all natural and man-made sources is about 350 mrems.

Radiation

Radiation Source	Amount of Radiation (mrem/year)
Tobacco Smoke (Two Packs/Day)[1 4]	8000
Cosmic (Sea Level)[2]	26
Cosmic (5280 ft)[2]	52
Within 50 Miles of a Nuclear Power Plant[2]	0.01
Within 50 Miles of a Coal-Fired Power Plant[2]	0.03
Flying (per hour)[2]	0.5
Luggage Inspection[2]	0.002
Watching TV[2]	1
Video Display Terminal (Computer Screen)[2]	1
Smoke Detector[2 3]	0.008
Luminous Watches[3]	N/A
Microwave[4]	1
Stone, Adobe, Brick or Concrete Building[2]	7

Radiation Source	Amount of Radiation (mrem/year)
Air[2]	200
Terrestrial (State Bordering the Gulf or Atlantic Coasts)[2]	16
Terrestrial (Colorado Plateau Area)[2]	63
Terrestrial (Elsewhere in the Continental US)[2]	30
Cooking w/ Natural Gas Stove[5]	6 to 9
Bananas (1/day)[6]	2.6
8oz Orange Juice (1/day)[6]	2.5
Medium Baked Potato (1/day)[6]	4.3
1 Cup of Raisin Bran (1/day)[6]	1.8
Double Hamburger (1/day)[6]	2.9
Large French Fries (1/day)[6]	4.7
One Cup of Cantaloupe (1/week)[6]	0.4
One Cup of Spinach (1/week)[6]	0.6

Body Count

Cause	Location	Percentage	Annual Deaths
Heart Disease(2006)	U.S.	28.50%	684,945
Cancer(2006)	U.S.	22.80%	547,956
Stroke(2006)	U.S.	6.70%	161,022
Microbial Agents(2000)	U.S.	3.12%	75,000
Toxic Agents(2000)	U.S.	2.29%	55,000
Adverse Reaction to Prescription Drugs(2000)	U.S.	1.33%	32,000
Suicide(2003)	U.S.	1.27%	30,622
Deaths Related to Coal Mining(2000)	U.S.	1.24%	30,000
Incidents Involving Firearms (2000)	U.S.	1.21%	29,000
Homicide(2003)	U.S.	0.08%	20,308
STD's(2000)	U.S.	0.08%	20,000

Cause	Location	Percentage	Annual Deaths
Traffic Accidents[24](2006)	U.S.	1.80%	26,347
Accidental Poisoning[25] (2006)	U.S.	0.70%	16,823
Falling[26](2006)	U.S.	0.66%	15,862
Tobacco Smoking[27] (2000)	U.S.	18.10%	435,000
Poor Diet and Physical Inactivity[28](2000)	U.S.	16.60%	365,000
Alcohol[28](2006)	U.S.	3.50%	85,000
Aviation[31](2007)	U.S.	>0.01%	640
Heart Disease[33](2004)	Worldwide	12.20%	7,200,000
Stroke[34](2004)	Worldwide	9.70%	5,710,000
Illicit Drug Use(2003)	U.S.	0.07%	17,000
Traffic Accidents(2004)	Worldwide	2.20%	1,270,000

Body Count

- **Total deaths from nuclear energy since 1986**

  0

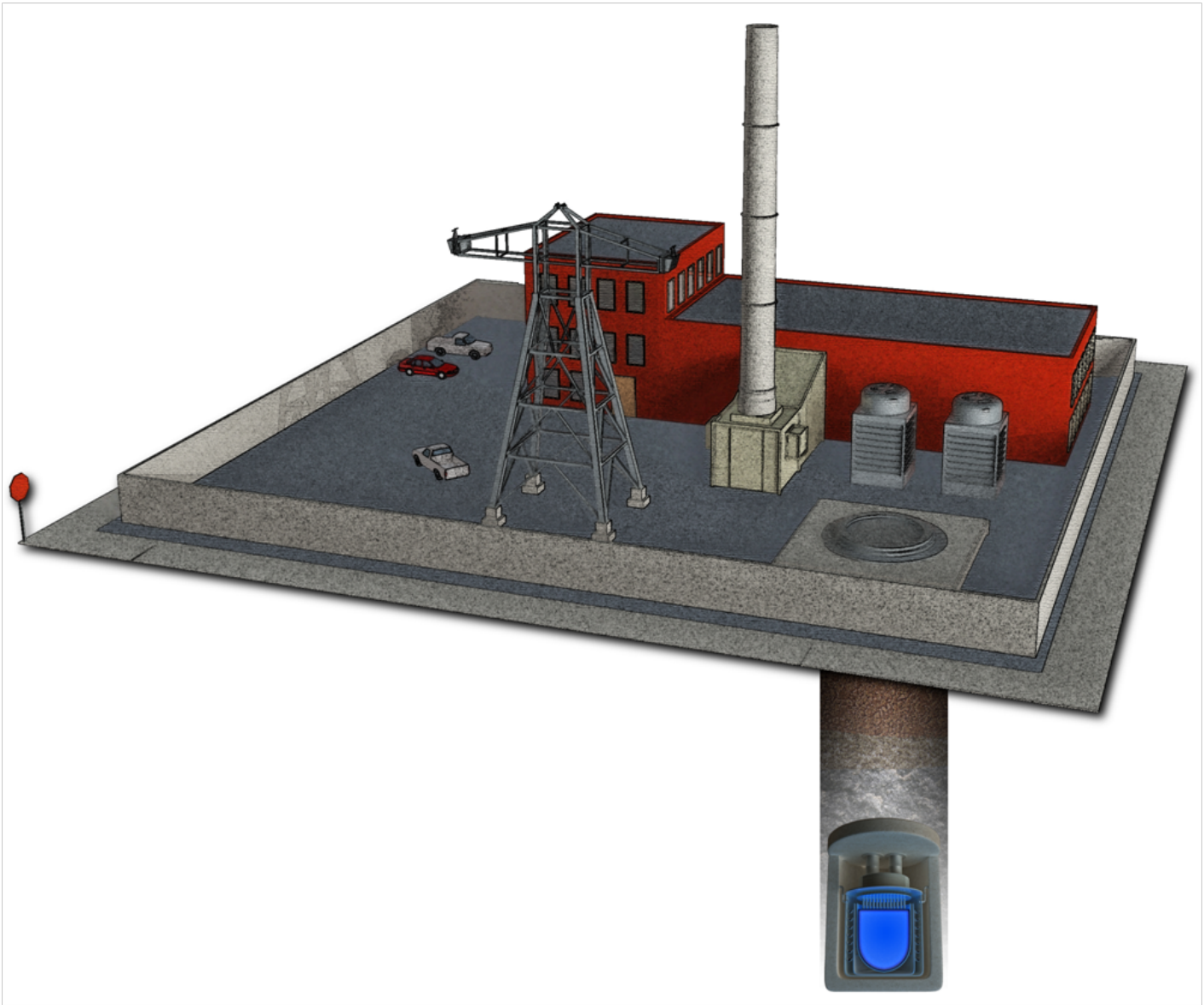
- **Total deaths from nuclear energy since start of civilian power**

  56

Distributed Power

- **Centralized production is site specific**
  - **Economic, health, safety, and geography**
- **Distributed power generates electricity from smaller sources, near power use**
  - **Wind, solar, some hydro, and now nuclear**
  - **Has co-gen advantages (district heating)**

Distributed Power



SMRs

- **Smaller than Big Nuc**
  - **10 MW to 150 MW**
- **Latest "old" technology**
  - **Definition of "space ready"**
- **Inherently safe**
- **Designed for specific purposes**
  - **Modular, factory built, single design**

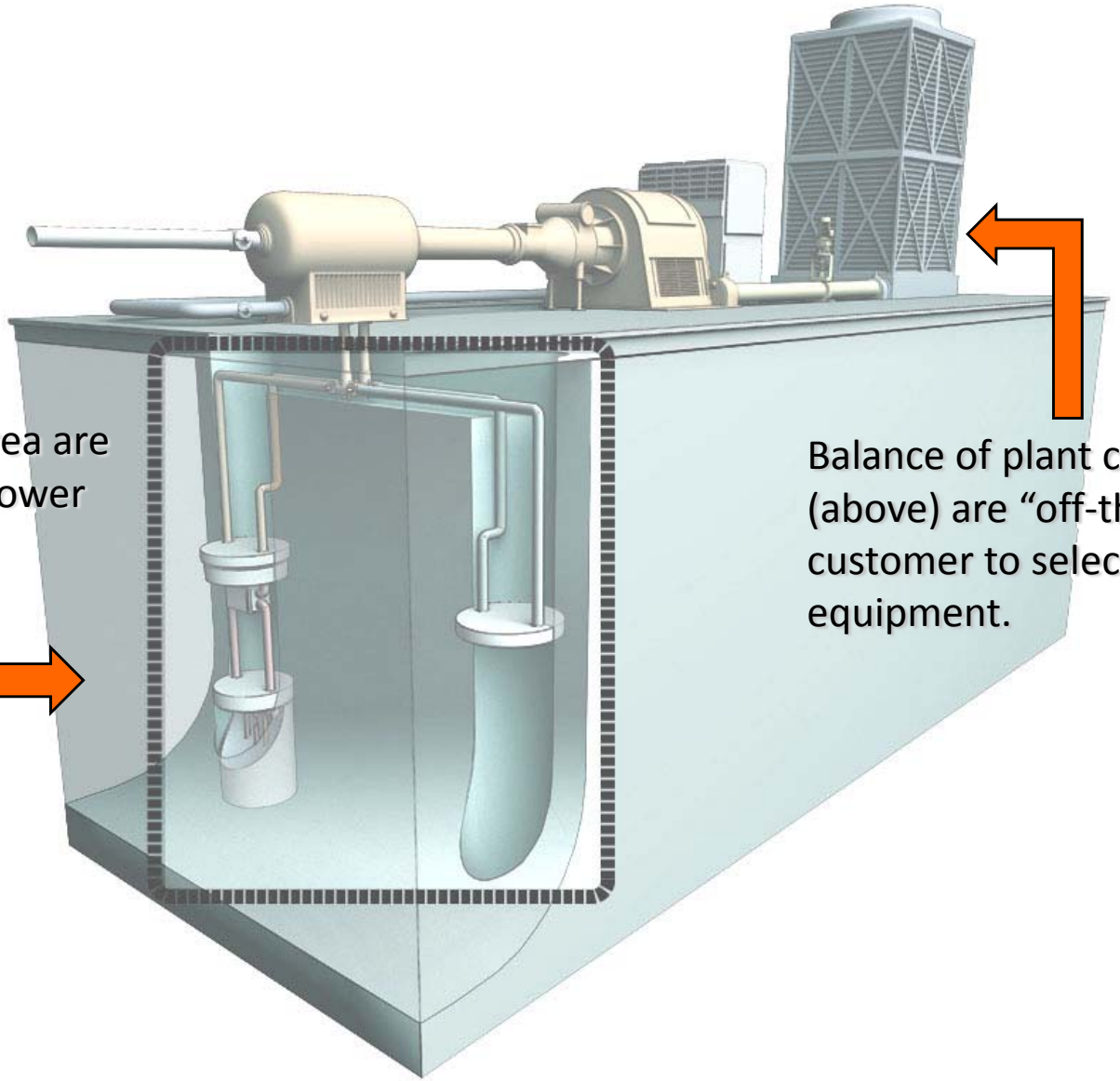
SMR Examples

- **Toshiba 4S**
- **NuScale**
- **PBMR**
- **B&W mPower**
- **Hyperion**

Hyperion Power Module

Reactor Power	70MW $_{thermal}$
Electrical Output	27MW $_{electric}$
Lifetime	7 – 9 years
Size (metres)	1.5w x 2h
Volume (m^3)	10
Weight (ton)	Less than 25
Structural Material	Stainless 316
Coolant	Pb / PbBi
Fuel	U, UH3
Enrichment (% U-235)	<12%
Refuel on Site	No
Refuel Frequency	7 – 9 years
Reactivity Control	H_2/D_2 gas control
Sealed	Yes
License	Begin Sept 2009
Passive Shutdown	Yes
Active Shutdown	Yes
Transportable	Yes
Factory Fueled	Yes
Safety & Control Elements	Non-mechanical. Chemistry based.
Internal Pumps	Zero
Total Cost (electric)	$45-$55 million USD
Total Cost (heat)	$30 million USD
Cost $/KW $_{electric}$	$1,666 – $2,037 USD
Cost $/KW $_{thermal}$	~$429 USD

Hyperion Power Module Electric Generation



Components in this area are specific to Hyperion Power Generation.

Balance of plant components (above) are “off-the-shelf” allowing customer to select preferred equipment.

Hyperion Power Module

- **Provides 70 Megawatts of thermal energy, or approximately 27 Megawatts of electricity**
- **Only 1.5 meters wide and 2 meters tall**
- **Safe – uses a unique, low-enriched uranium fuel**
- **Cannot go supercritical or "melt down"**
- **Produces power for 5 to 7 years depending on use**
- **Permanently sealed at the factory**
- **Sited underground out of sight – inconspicuous**
- **Is proliferation-resistant; never opened once installed**
- **Has no moving parts in the core to break down**
- **Requires less supervision with easier operation & monitoring**
- **Returned to the factory for re-fueling**
- **Transported via ship, rail, or truck**
- **Can be teamed with more HPMs for greater power**
- **Will be licensed by the U.S. Nuclear Regulatory Commission**

Licensing

- **U.S. Nuclear Regulatory Commission**
  - **NRC created three steps as optional paths**
    - **Early Site Permit**
    - **Design Certification**
    - **Combined Operating License**
- **Outside U.S.**
  - **Most countries will accept design certification from country of export**
- **U.S. DOE NNSA**
  - **1-2-3 Agreements**

U.S. DOE 1-2-3 Agreements

- **Section 123 U.S. Atomic Energy Act of 1954,**
  - **agreement for cooperation as a prerequisite for nuclear deals between the US and any other nation**
  - **Such an agreement is called a 123 Agreement.**
  - **To date, the U.S. has entered into ~ twenty-five 123 Agreements**

U.S. DOE 1-2-3 Agreements

- **Eurotom: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom**

- **Argentina, Australia, Bangladesh, Brazil, Canada, China, Colombia, Egypt, India, Indonesia, International Atomic Energy Agency (IAEA), Japan Kazakhstan, Republic of Korea, Morocco, Norway, South, Africa, Switzerland, Taiwan, Thailand, Turkey, Ukraine, (UAE)**

Plant Economics

- **Electricity from most SMRs will cost more**
  - **Hyperion is exception**
- **Issues abound**
  - **Refueling**
  - **Transport**
  - **Security**

GNEP Grid Appropriate Reactors

- **Fuel designs that lend to no-refueling on site**
- **IAEA safeguards for non-proliferation that include remote monitoring**
- **Physical protection against sabotage and terrorist acts**
- **Standardized design in the 50 to 350 MW range**
- **Potential for district heating and industry and potable water production**
- **Fully passive safety systems**
- **Simple to operate, requiring minimal nuclear infrastructure**
- **Use of as much existing licensed or certified technology as possible**
- **Use of advanced manufacturing techniques**
- ***Hyperion Power Module is the only SMR that meets all of these requirements***

Applications

- **Mining**
- **Oil production & refining**
- **Remote communities**
- **Military facilities**
- **Dedicated power**
  - **hospitals, factories, foundries, government centres, water treatment, irrigation, universities**

Site Selection Criteria

- **SMRs are most appropriate**
  - **Outside established grid**
  - **Where no power infrastructure exists**
- **Still must have zone of containment**
  - **Security**
  - **Safety**
  - **No different than other small power generation**
    - **Diesel, heavy oil, solar, wind**

Electric Generation Comparisons

	Greenhouse Gas Emitting	Dependable (Baseload)	Sustainable	Environment Impact	Cost
Coal	High	Yes	No	Very High	3.8¢ kWh[4]
Natural Gas	High	Yes	No	Very High	6.3¢ kWh[4]
Nuclear	None	Yes	Yes	Minimal[1]	2.5¢- 4.2¢ kWh[4]
Solar PV	Moderate[2]	No	No[3]	Moderate[2]	35¢ kWh[5]
Biomass	High	No	No	High	8¢ kWh[5]
Wind	Minimal[2]	No	Yes	High	7.4¢ kWh[5]
Hydro	None	No	???	High	4.5¢ kWh[6]

[1]From uranium mining
[2] In manufacturing
[3] Supplies of useful silicon for PV cells are already strained
[4]http://world-nuclear.org/info/inf02.html
[5]http://www.solarbuzz.com/StatsCosts.htm
[6]http://zebu.uoregon.edu/2001/ph162/l14.html

Follow-up

- coo@HyperionPowerGeneration.com
- http://www.nei.org
- http://www.HyperionPowerGeneration.com
- http://www.mondoenergy.org
  - (coming soon)
- CO2 Emissions & Public Policy
  - Roger Pielke, University of Colorado
  - http://rogerpielkejr.blogspot.com
  - http://e360.yale.edu/content/feature.msp?id=2175