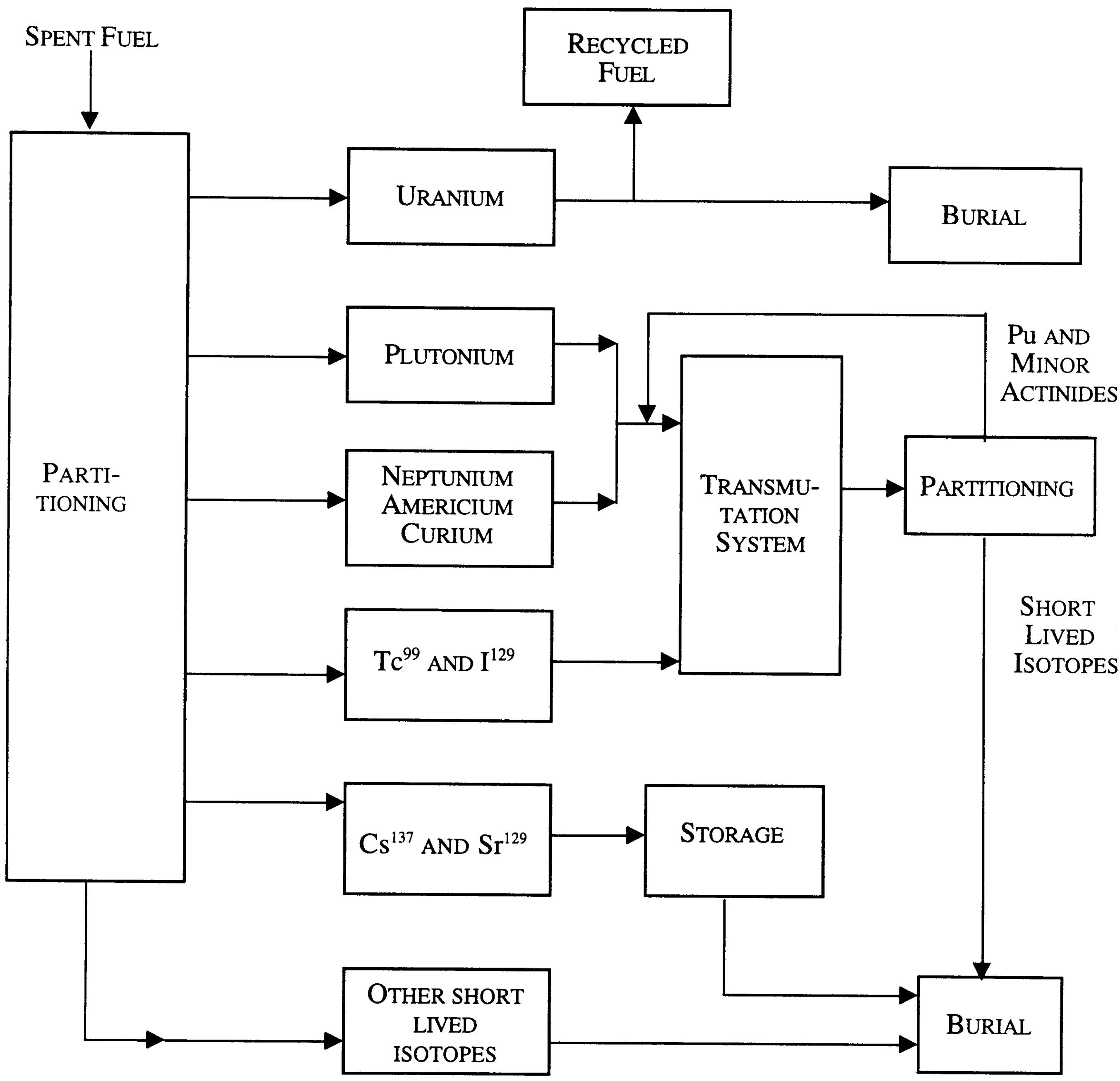
TRANSMUTATION TECHNOLOGY OPTIONS

Mujid S. Kazimi
Department of Nuclear Engineering
Massachusetts Institute of Technology

D.O.E. ATW Meeting
Washington, D.C.
February 17, 1999

Transmutation of Nuclear Wastes



Major Choices for Transmutation

- Neutron spectrum
- Fuel composition
- Coolant choice
- Accelerator driven or critical

PROPOSED SYSTEMS FOR NUCLEAR TRANSMUTATION

	Thermal Spectrum	Fast Spectrum
Reactor or Critical Systems	Light Water	Na Cooled
	Heavy Water	Pb Cooled
Accelerator Driven or Subcritical Systems	Aqueous	
	Solid Fuel	Pb Cooled

COMPARATIVE NEUTRONICS OF PWR AND LMR, ATW

	PWR	LMR	ATW*
ELECTRICAL POWER, MW	1,000	1,000	800
PLANT EFFICIENCY	32 %	40 %	40% 35% to grid
CORE DIMENSIONS:			
HEIGHT (m)	3.5	1.5	1.5
DIAMETER (m)	4.2	3.0	3.0
VOLUME (m^3)	~40	~10	10
FUEL FRACTION IN CORE	~25 %	~30 %	~30 %
FISSILE INVENTORY, kg	3,000	3,000	2,000
ENRICHMENT	4 %	16 %	60 %
POWER DENSITY kW/liter	75	400	340
BURNUP MWD/kg	40	100	<65
FERTILE/FISSILE FISSION	.04	.20	.30
$k_{effective}$	1.0	1.0	.95

*Based on presentation at MIT, Jan., 1998

Possible Fuel Materials

- Metallic fuel for fast spectrum:
  building on IFR and Navy experience
- Oxidic inert fuel for thermal spectrum:
  building on LWR experience
- Aqueous fuel for thermal spectrum:
  building on molten salt reactor experience of 60s

Fuel Composition Considerations

1. Compatibility with neutron spectrum
2. Material limits under irradiation
3. Separation inventory (time)
4. Reactivity control requires absorber addition
   - Poison
   - Thorium
5. Incorporate other spent fuel elements
   - Zr from clad
   - Tc-99

Attributes of Lead over Sodium

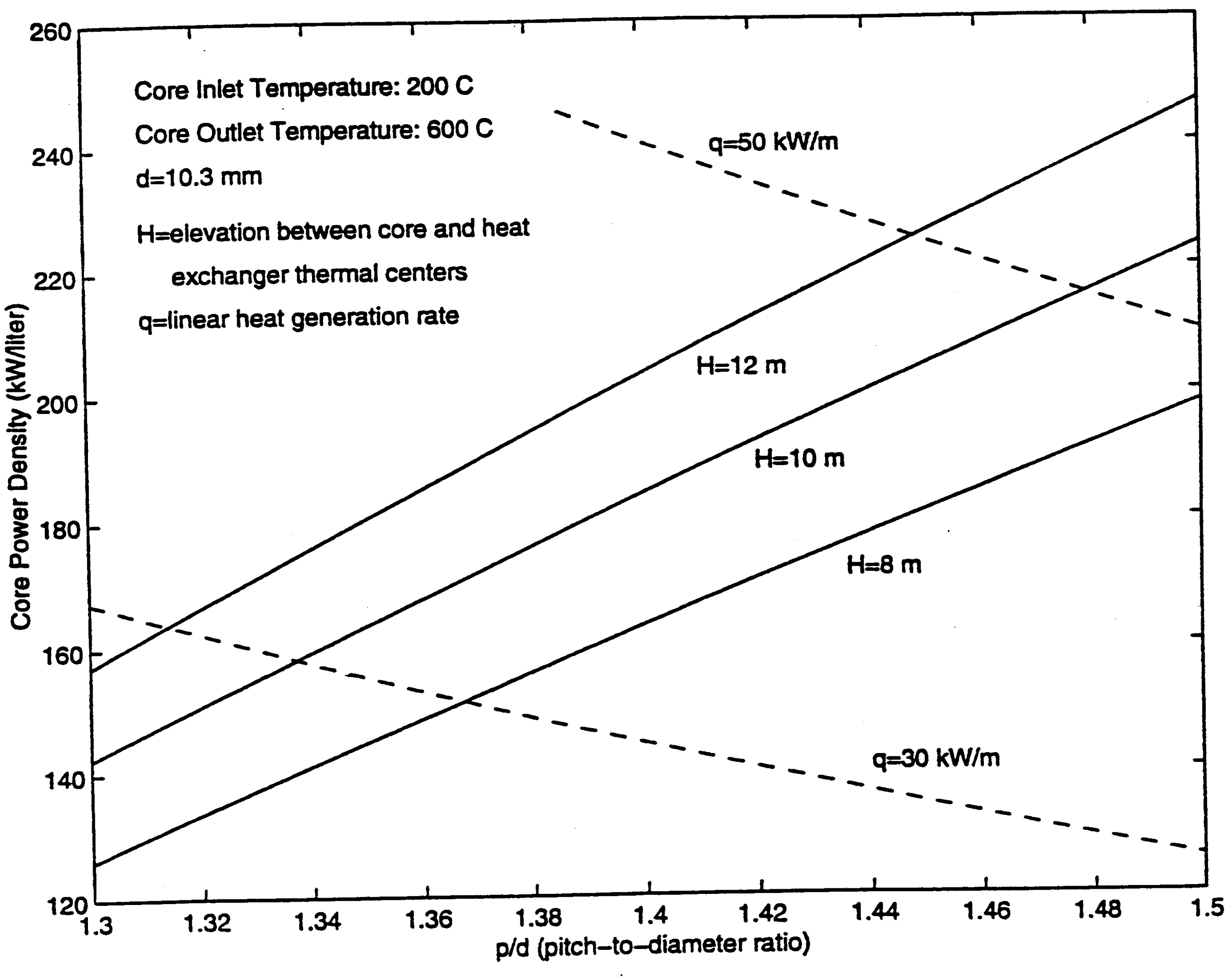
1. Chemically inert
2. Harder spectrum improves neutron economy
3. Easily designed to provide negative coolant reactivity coefficients
4. Higher boiling point (1725˚C vs 892˚C). Avoids coolant voiding during transients
5. High potential for natural circulation
6. Higher shielding capability against γs
7. Lead retains most actinides and fission products should an accident occur.

Attributes of Sodium over Lead

1. Lower density $\Rightarrow$ structural design cost
2. Less expensive as a material (especially in comparison to Pb-Bi)
3. Less biologically hazardous
4. Less radioactivity (no polonium)
5. Less demanding corrosion chemistry

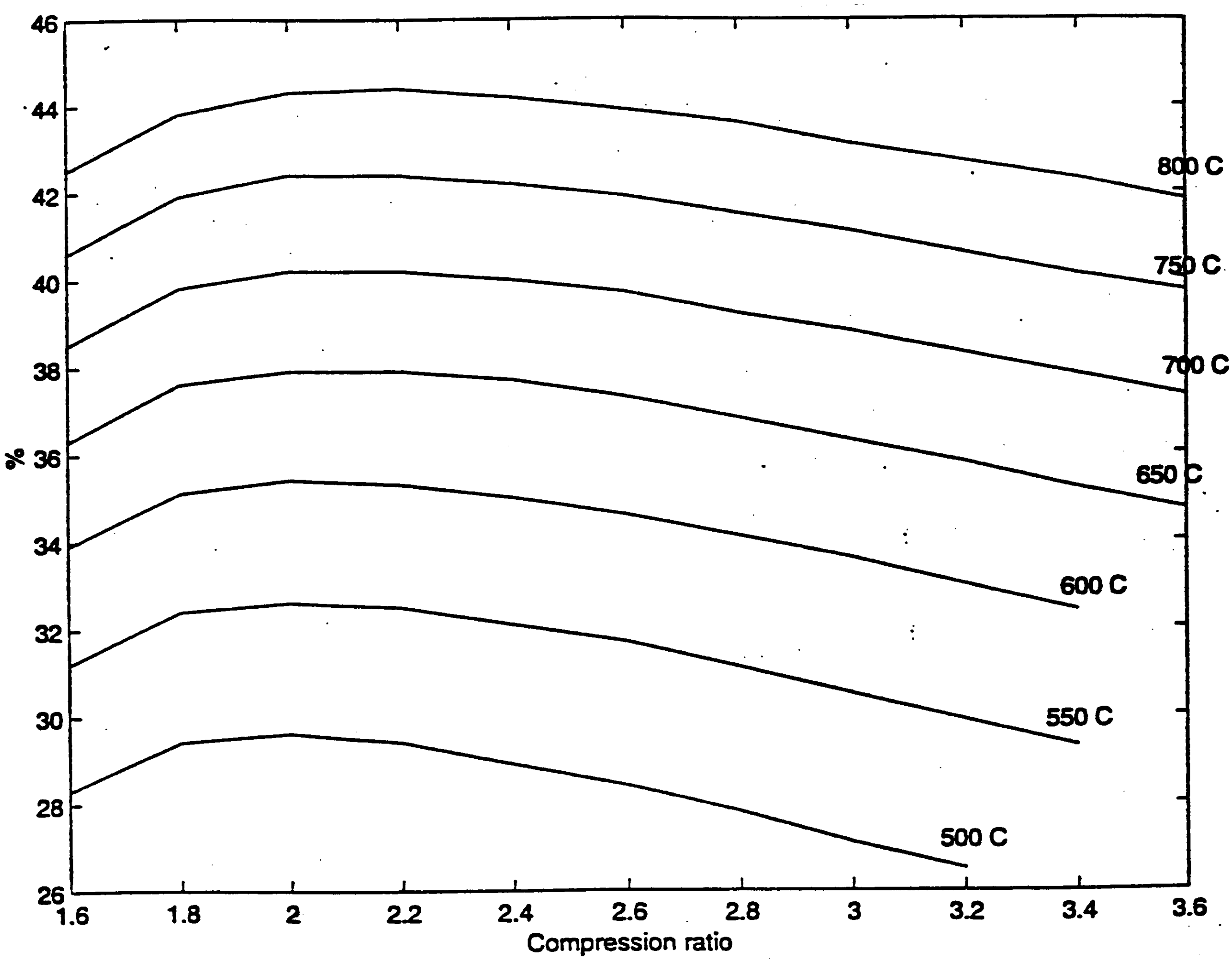
COMPARISON OF COOLANTS FOR NATURAL CIRCULATION

Coolant	Reactor	Tin/Tout (^{o}C)	Driving Head ($\Delta\rho$)		Heat Capacity (ρc_p)		Margin to Boiling ($T_{boil}-T_{out}$)	
			g/cm^3	normalized	J/m^3K 10^6	normalized	°C	normalized
Pb-Bi eutectic	ATW	340/510	0.205	1	1.53	1	1160	1
Pb	BREST	420/540	0.146	0.71	1.50	0.98	1185	1.02
Na	CRBR	388/535	0.036	0.18	1.08	0.71	350	0.30
H_2O	4 loop PWR	283/325	0.073	0.36	2.93	1.91	18	0.02



Thermal-hydraulic performance map for naturally circulating Pb-Bi reactors

Thermal efficiency for various inlet gas temperature and compression ratio



R&D Needs of Transmutation Systems

1. Materials Lifetime Assessment

— **Compatible with coolants at 500-800 °C**

— **Capable of withstanding high fluences**

✶ **Specifically for accelerator driven systems**

— **Window design**

— **Effects of spallation products on corrosion**

R&D Needs of Transmutation Systems

2. Pyrochemical Fuel Separation Technology
   - **Industrial scale recovery rate of MA > 99 %**
   - **Industrial scale recovery of Pu and U > 99.9 %**
   - **Separation of Tc-99**
   - **Separation of I-129**

R&D Needs of Transmutation Systems

3. Fuel Performance and Core Design

   - **Metallic fuel (Pu-Zr) irradiation behavior up to 100 MWD/kg**
   - **Inert matrix inclusion of absorbers to introduce negative doppler and to control reactivity depletion**
   - **Fuel assembly design to introduce spectral shift approach to reactivity swing compensation**

R&D Needs of Transmutation Systems

4. System Optimization Studies
   - **Critical systems vs ADS**
   - **Natural vs forced convection systems**
   - **Steam thermal cycle vs gas thermal cycle**
5. Liquid Lead and Lead Bismuth Technology
   - **Corrosion control**
   - **Purification needs**
   - **Thermal-hydraulic behavior**
6. Accelerator efficiency for high current (20-50 mA) operations

TECHNOLOGY BENEFITS OF ATW DEVELOPMENT

	Neutron Science	Isotope Production	Defense Waste	Commerical Waste	Energy Production
Accelerator	√	√	√	√	√
Spallation Target	√	√	√	√	√
Separation Technology		√	√	√	√
Lead Coolant Technology			√	√	√