

Magnetic Refrigeration

Energy Efficient

Environmentally Friendly

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Astronautics

Corporation of America



Astronautics Corporation of America

Magnetic Refrigeration

- **Magnetic Refrigeration-**
How it works
- **Recent Developments**
 - First High Efficiency, High Power Room Temperature Device
 - First Successful Permanent Magnet Room Temperature Device
- **Specific Application-**
Automobile Seat Cooler



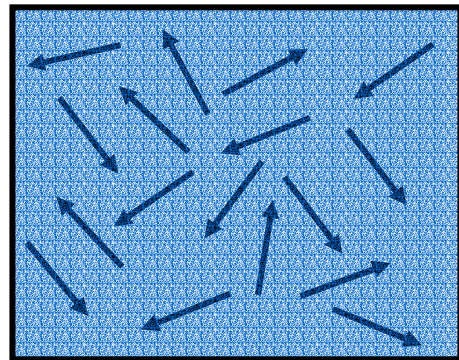
Astronautics Corporate Overview

- **Privately held company founded in Milwaukee WI in 1959**
 - >2000 employees
- **Avionics, Display Systems & Navigation Systems**
- **Experts in electro-mechanical systems for military and commercial applications**
- **Created the only guidance system still in operation outside the solar system**



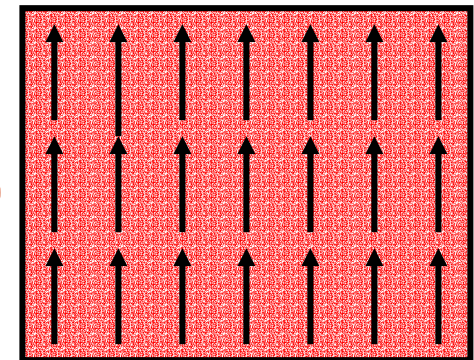
How Magnetic Refrigeration Works: Magnetocaloric Effect

Apply magnetic field
spins align
temperature increases



$B \sim 0$

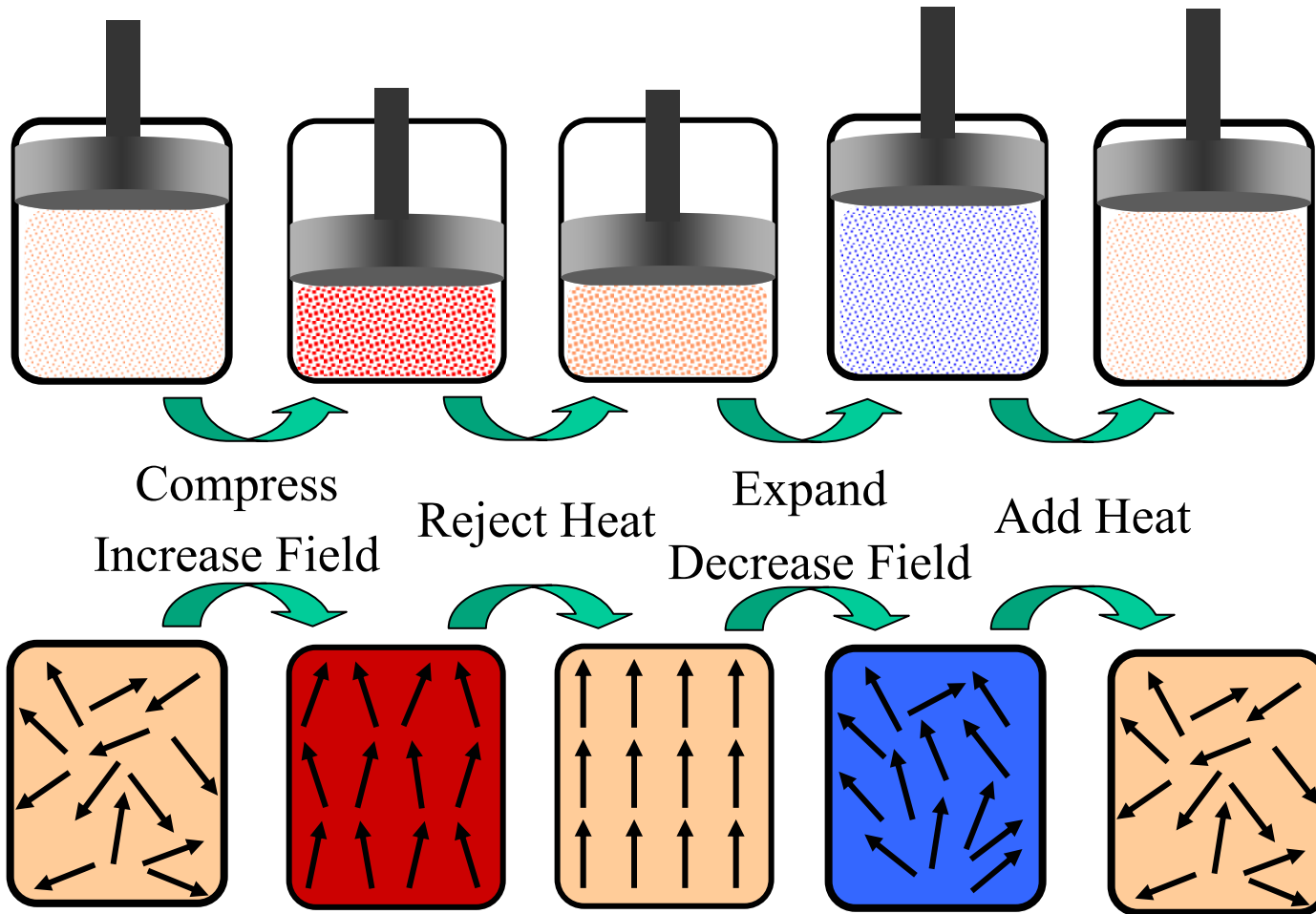
$B > 0$



Remove magnetic field
spins randomize
temperature decreases



Magnetic Refrigerator Vapor Compression Analogy



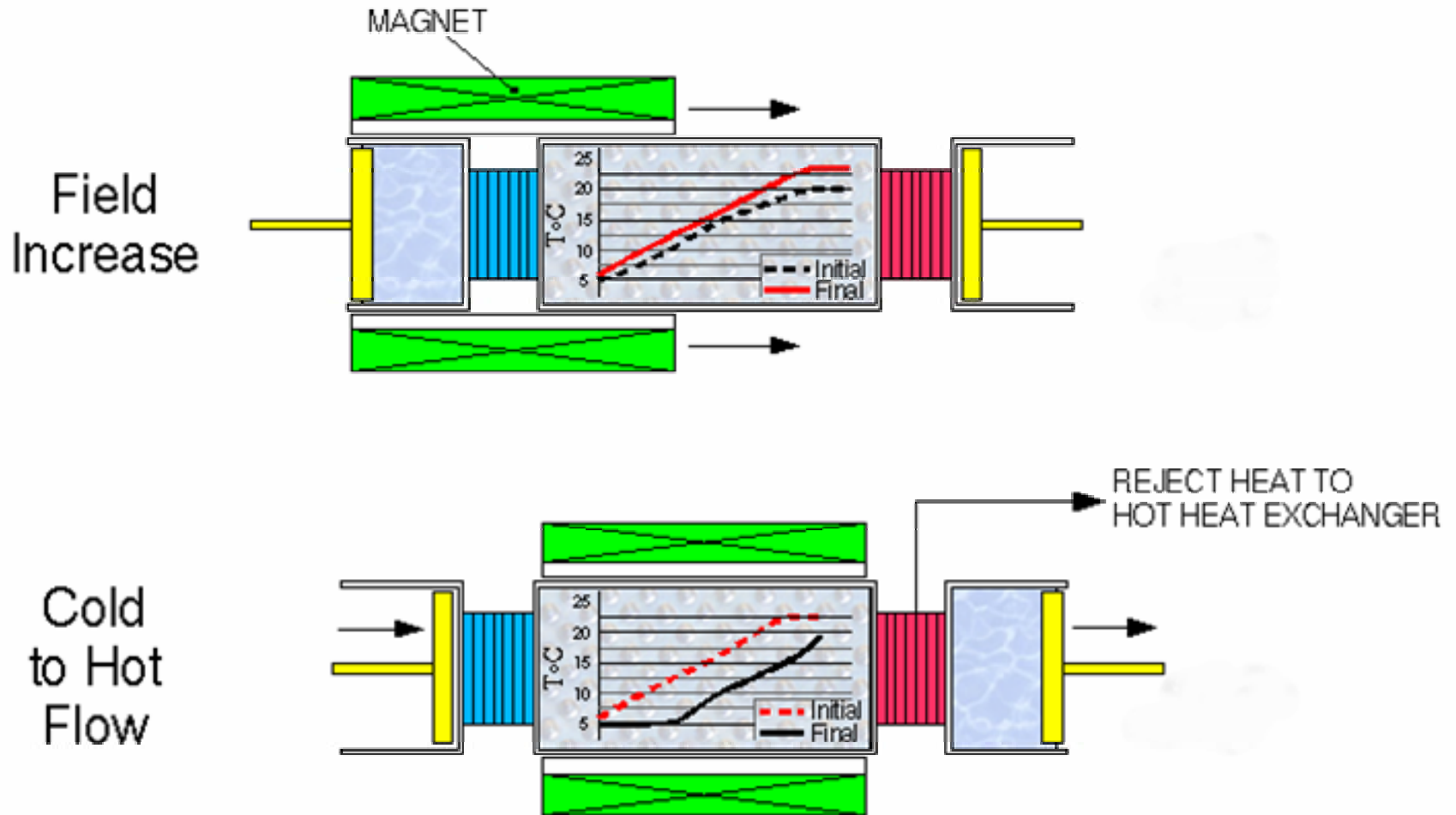


Magnetic Refrigerator Design Challenges

- **Magnetocaloric effect is small**
 - 2 to 10 C
 - Regeneration required
- **Solid refrigerant**
 - Heat transfer fluid flow required
- **Strong magnetic field needed**
- **Moving bed or field needed**

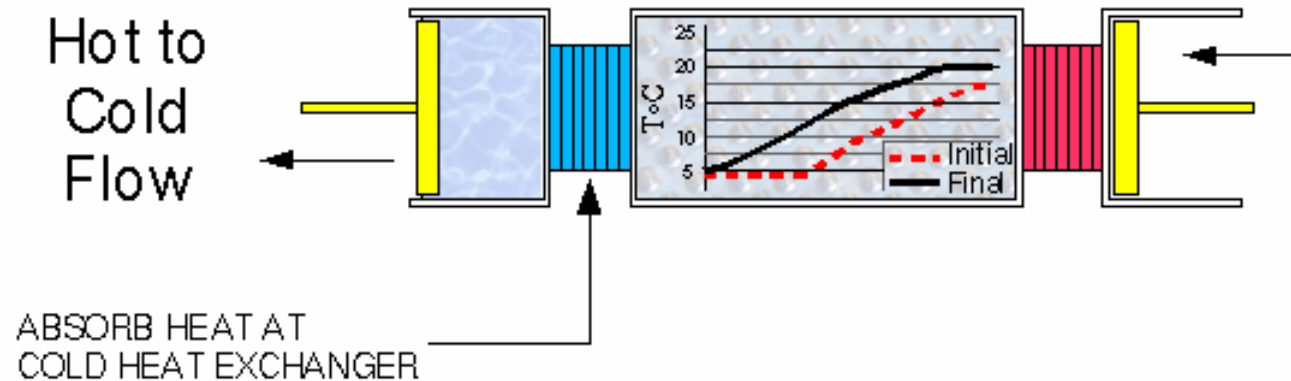
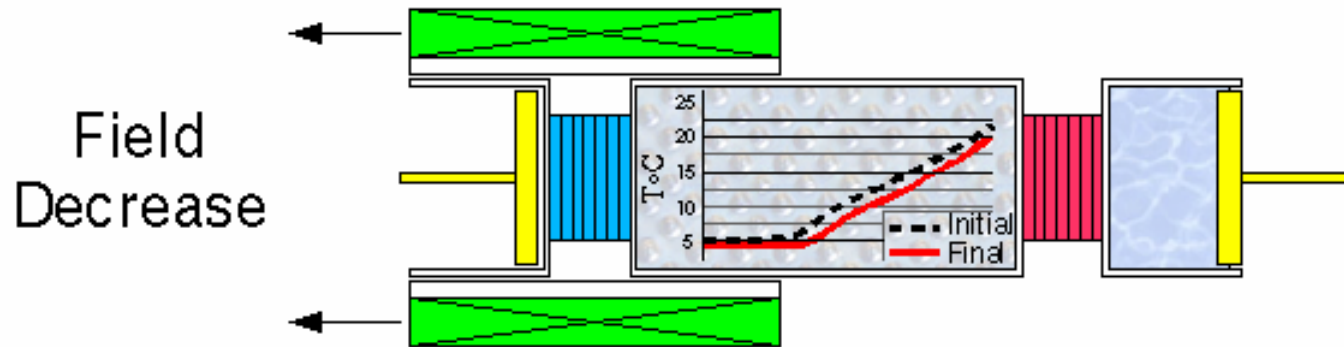


Active Magnetic Regenerator Cycle





Active Magnetic Regenerator Cycle





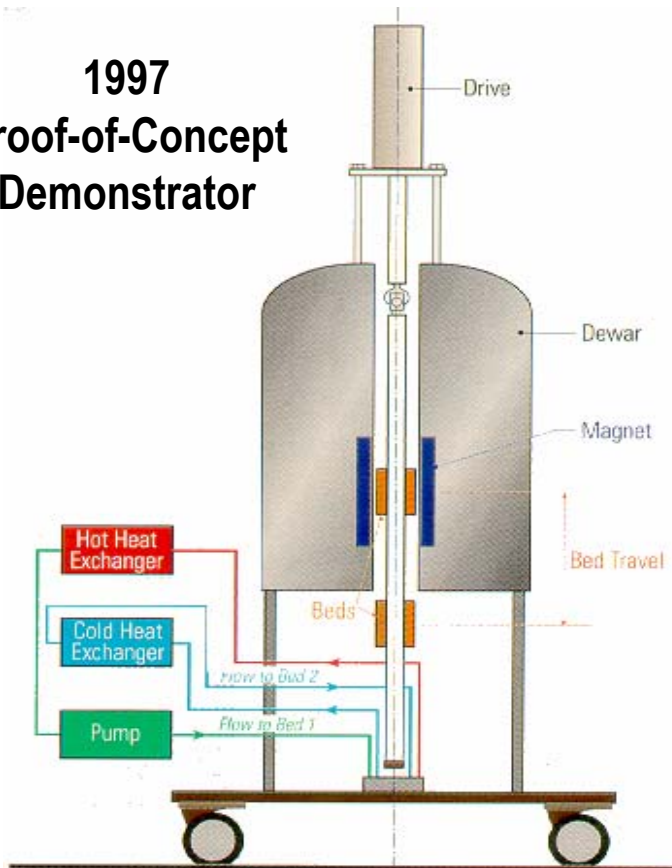
Magnetic Refrigeration Technology Development Timeline

- 1926 Magnetic refrigerator proposed by Debye and Giauque**
- 1949 Nobel Prize awarded to Giauque for magnetic refrigeration**
- 1978 Los Alamos DOE Lab patents “AMR” magnetic refrigerator**
- 1989 Navy demonstrates “AMR” magnetic refrigerator**
- 1991 Astronautics demonstrates 40 K high efficiency AMR**
- 1997 Astronautics demonstrates high power NRT AMR**
- 2000 Giant Magnetocaloric Effect alloys made by Ames DOE Lab**
- 2001 Astronautics demonstrates permanent magnet rotary AMR**



1997 Proof of Concept (POC) Near Room Temperature Magnetic Refrigerator

1997
Proof-of-Concept
Demonstrator



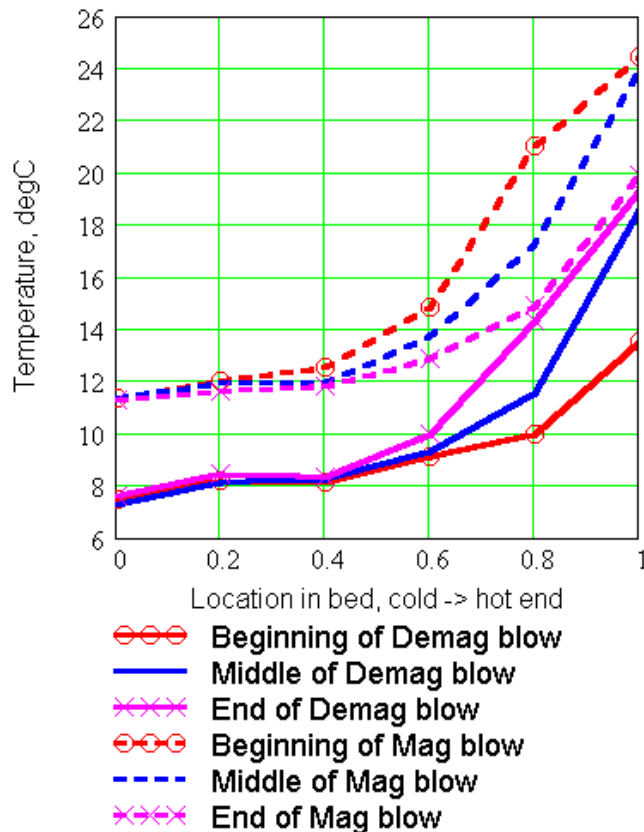
- **Approach**

- Utilized a readily available superconducting solenoid magnet
- Reciprocating system
 - Mechanically simple
- Gadolinium spheres in regenerative bed
- Used water as heat transfer medium



1997 Proof of Concept Results

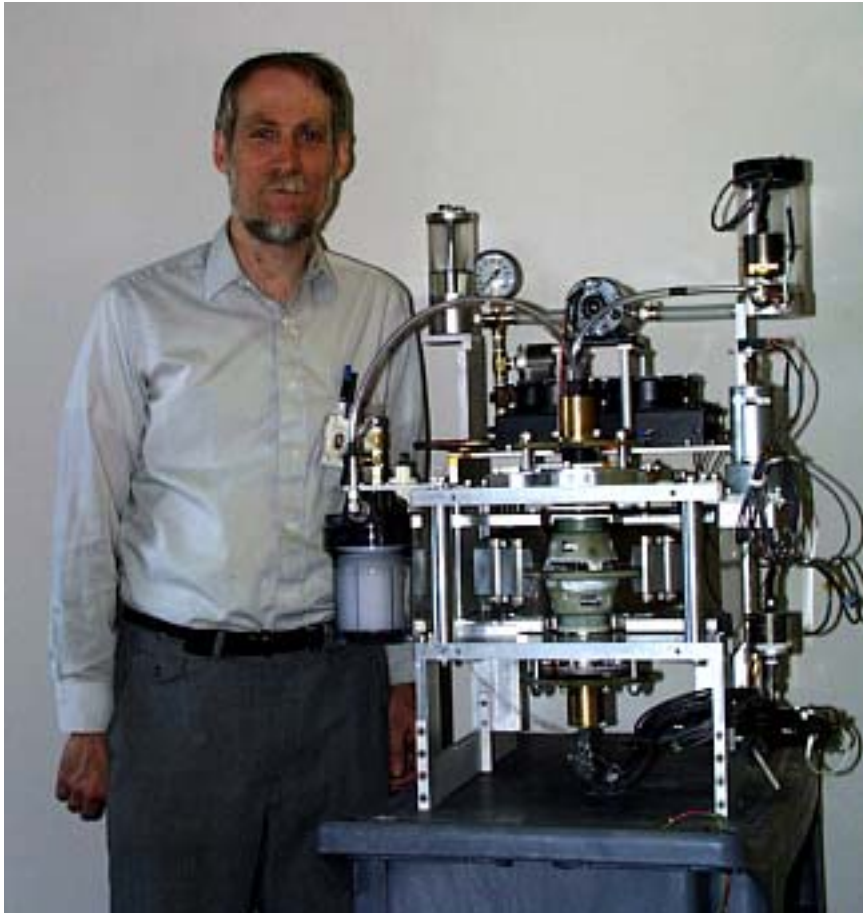
Measured Bed Temperatures



- ***Validated AMR Concept and Model***
- **Produced 100's Watts of cooling power**
 - An order of magnitude higher than prior systems
- **Produced temperature span five times the magnetocaloric effect**



Rotary Magnetic Refrigerator Near Room Temperature



- Approach
 - Permanent magnet
 - no Liquid He required
 - Continuously rotating wheel
 - Good torque cancellation
 - Low noise and vibration
 - High frequency operation
 - Gadolinium spheres in regenerative bed
 - Water is heat transfer medium



Rotary Magnetic Refrigerator Near Room Temperature

- *Demonstrated feasibility of permanent magnet based AMR*
- **Achieved 38 F span**
- **Battery powered**
- **Results are encouraging**
 - Ten-fold increase in frequency compared to reciprocating system
 - Identified parasitic losses
- **Path to improving performance identified**



Magnetic Refrigeration Automotive Seat Cooler

- **Retains high efficiency at small scale and small temperature span compared to vapor cycle**
 - Unique magnetic refrigeration feature
- **Cooling passengers via seats involves less load and less temperature span than cooling via cabin air**
 - Higher air temperature acceptable with cooled seats
- **Seat coolers improve occupant comfort and provide high-value market for first application**
 - Quickly cool seat surfaces before occupants enter vehicle
 - Device can switch to heating mode in cold weather



Magnetic Refrigeration Automotive Seat Cooler

- **Higher cooling system efficiency improves alternative-fuel vehicle range**
 - Seat coolers reduce output required from cabin air cooling system
- **Thermo-electric seat coolers with lower efficiency are already in production**
- **Safe and environmentally friendly**
 - Low pressure, aqueous coolant
 - Solid, non-global warming, non-ozone layer depleting refrigerant