Cryocooling in the 21st Century

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4K is routine

Today's cryocoolers can routinely cool from room temperature to 4K or less within ~ 90 mins of being switched on

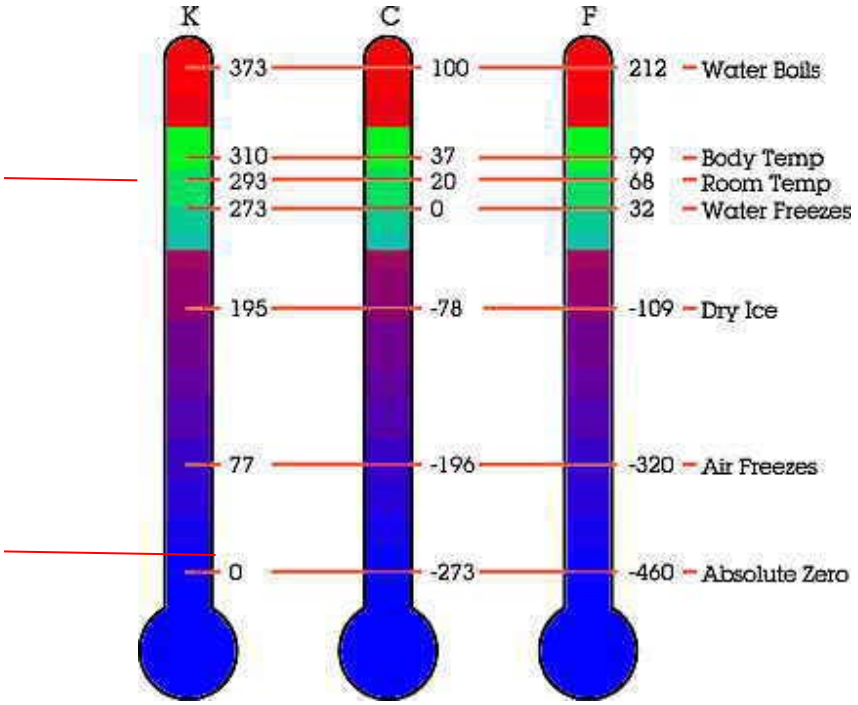
How many Watts of cooling are required?

Stefan–Boltzmann law : Heat Energy = $\varepsilon\sigma T^4$

1W at 4.2K (LHe temp) together with 100W at 77K (LN_2 temp)

PTR

GM



Early MRI

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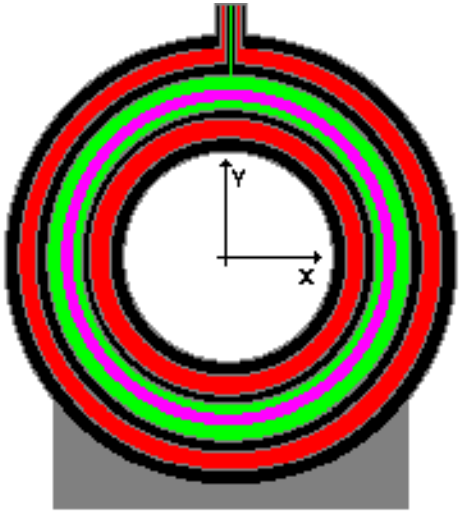
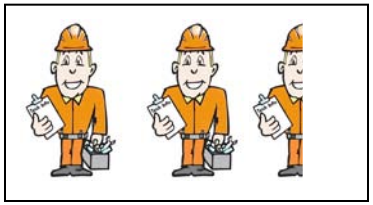


- Vacuum
- Liquid Helium
- Liquid Nitrogen
- Container & Support
- Superconducting Coil

Dealing With Liquid Cryogens in Magnets & Early MRI

Run Hours & Service Intervention

CAR ~ 6 years	Cryocooler	Domestic Fridge
60,000 miles	6 years	6 years
1500 hours	50,000 hours	50,000 hours
6 Services	2~3 Services	0 Services



Cryocooler Applications

10K GM Shield Cooler for MRI & Research Magnets

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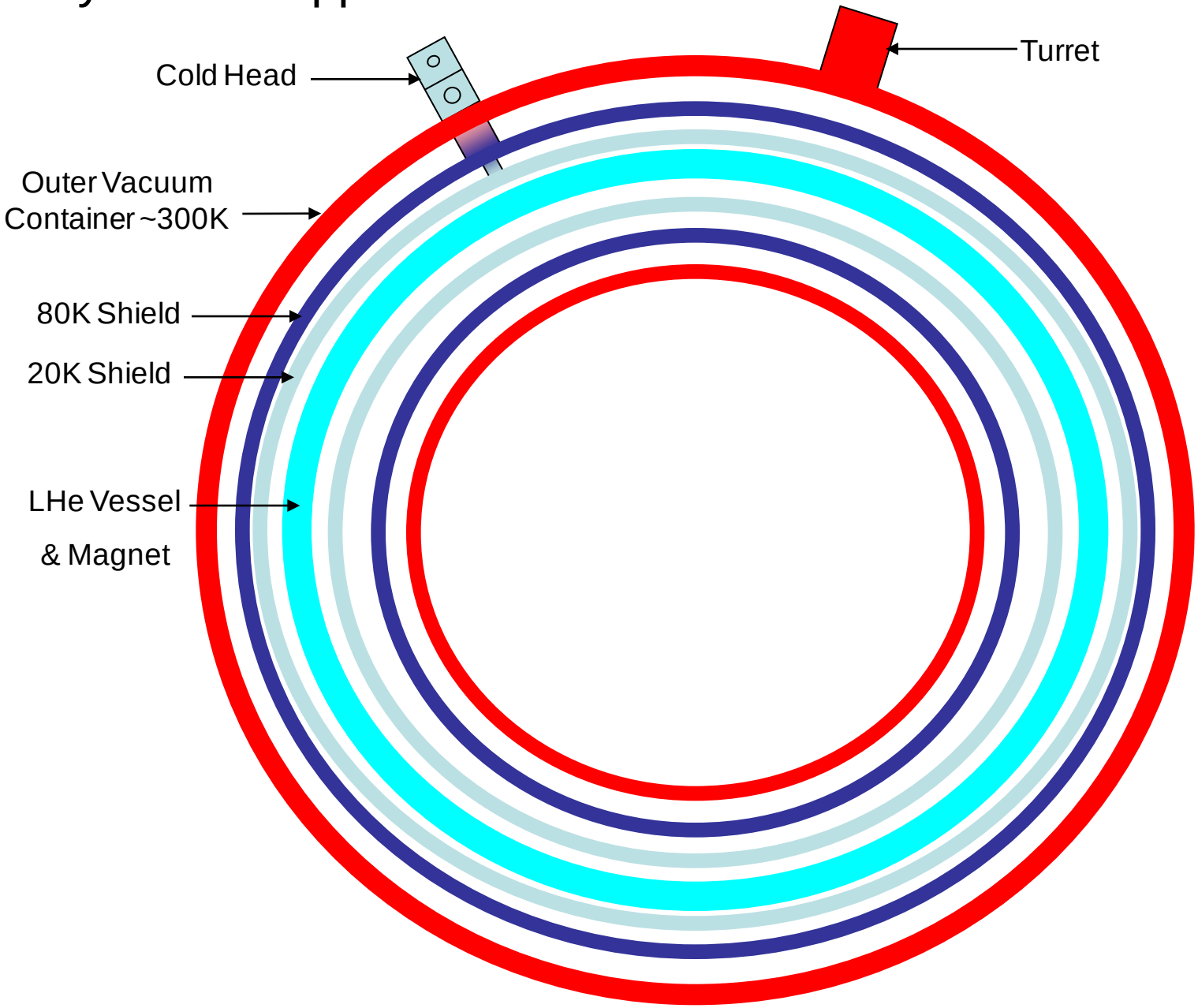

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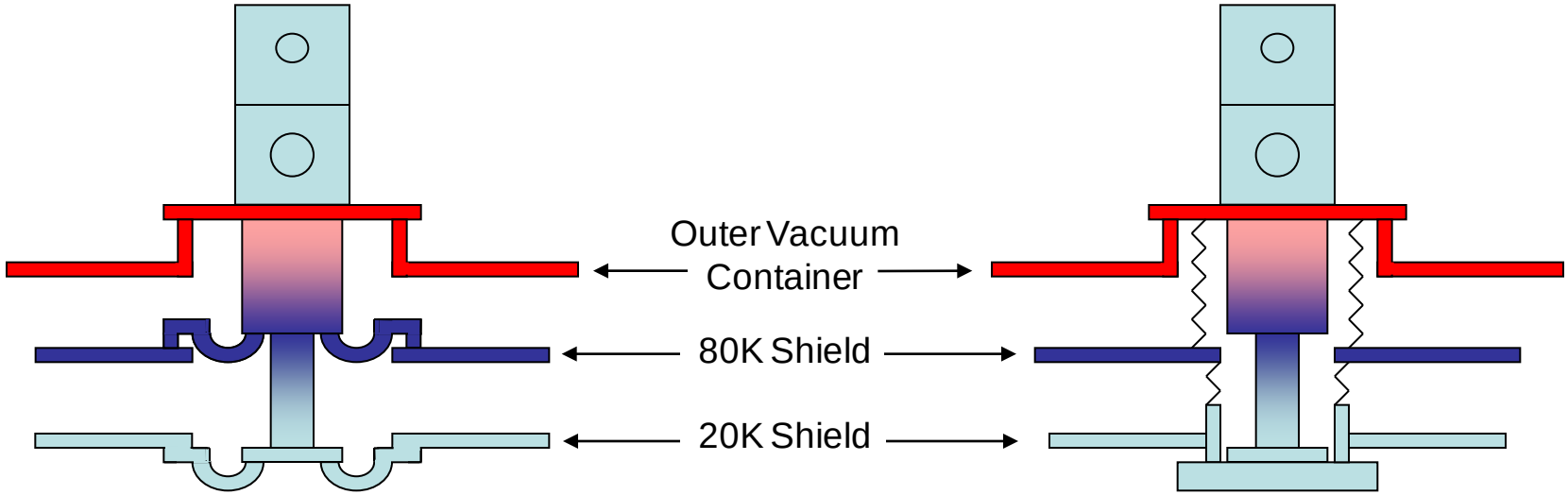
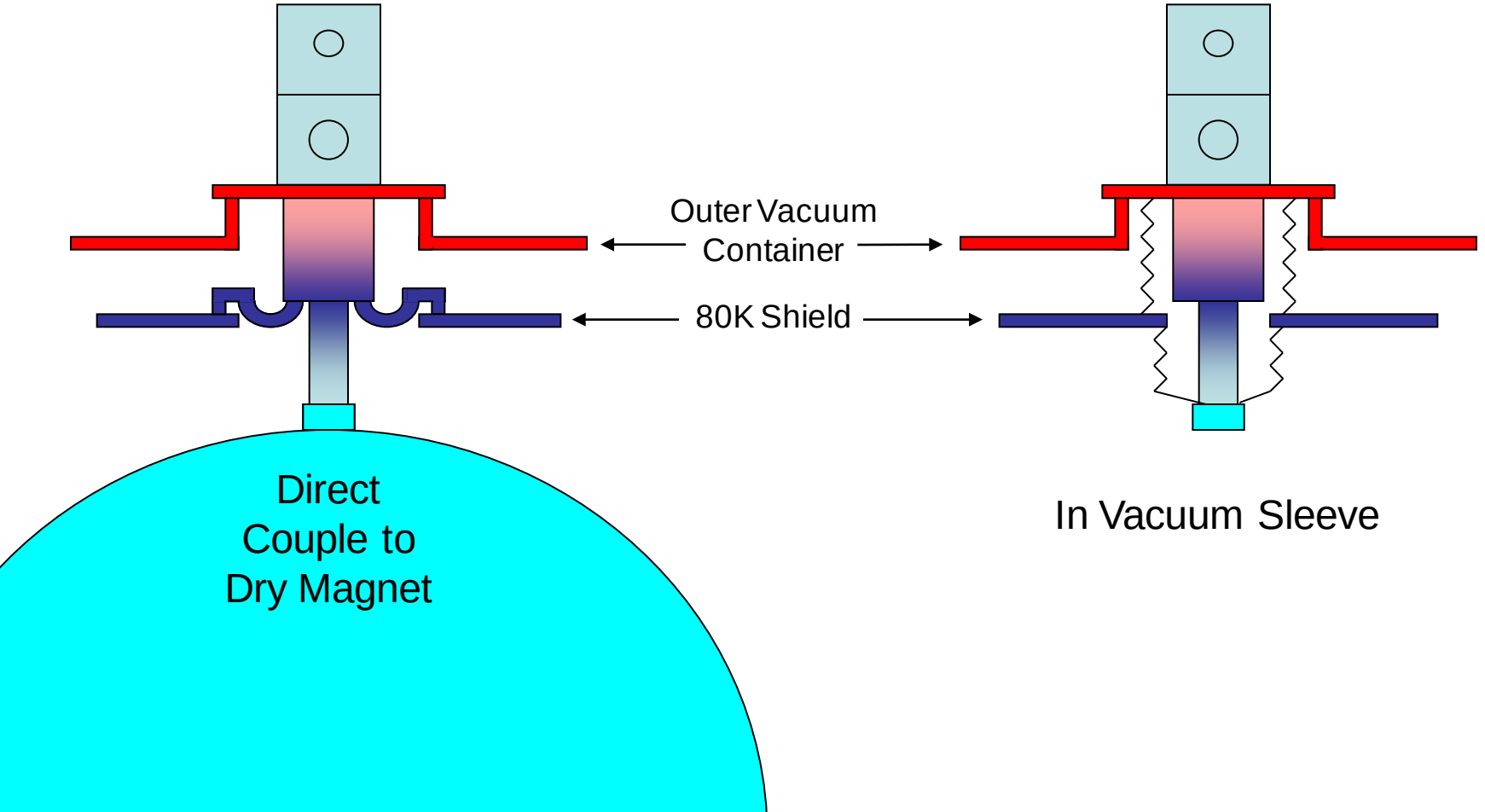


Cryocooler Applications

4K GM Recondensor for MRI & Research Magnets



Global Cryocooler Market Growth Drivers

- Cost & Convenience
  - Availability and cost of Helium
  - Conservation of Helium
  - Convenience
  - Health and Safety
  - Reduction of Operating Costs
  - Simplification of System design and Build
  - Reduction of system cost

Energy

- Cryocoolers have low thermodynamic efficiency (typically 1% or so)
- Therefore the main downside to the use of cryocoolers is the electrical requirement which in many devices is in the range of some kW.
- Cryocoolers do enable designs which save energy or material in other parts of the system.
- A full calculation to compare to the energy consumed to produce and transfer liquid cryogens to the point of use, keep them topped up etc is complex.
- Reduction of energy consumption is a worthy future goal for cryocooler development and some systems are already coming to market with this in mind

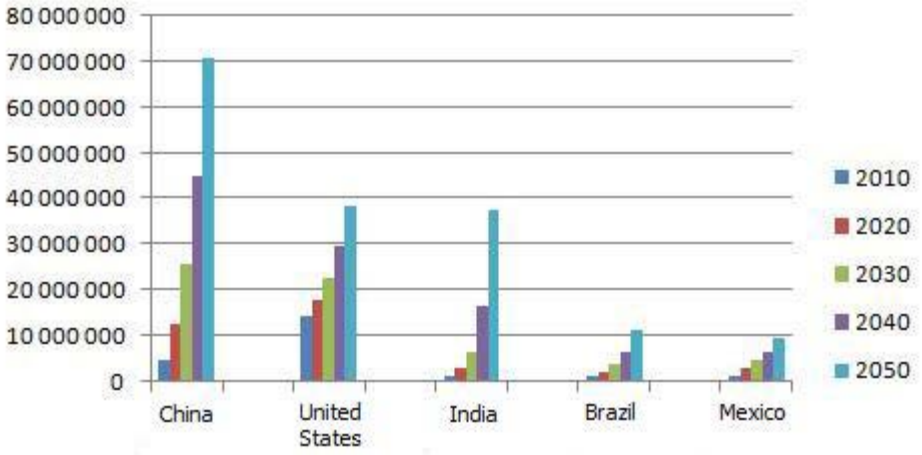
e.g. Sicera Cryopump

The Future: Emerging Markets BRICS(M) & VISTA

- **BRICS**: Brazil, Russia, India, and China
- These countries account for over 25% of the world's land coverage and 40% of the world's population
- Mexico and South Korea (sometimes added but not originally included because already more developed).
- **VISTA**: Vietnam, Indonesia, South Africa, Turkey, Argentina.
- Next Eleven (or **N-11**) are eleven countries—Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, the Philippines, South Korea, Turkey, and Vietnam

Strong Position for UK Cryogenic Manufacturers /Exporters

1. **High Expertise & Experience**
2. **Low Pound**
3. **Business Language for International Collaboration**



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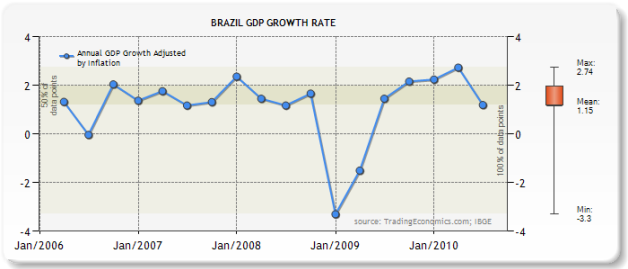
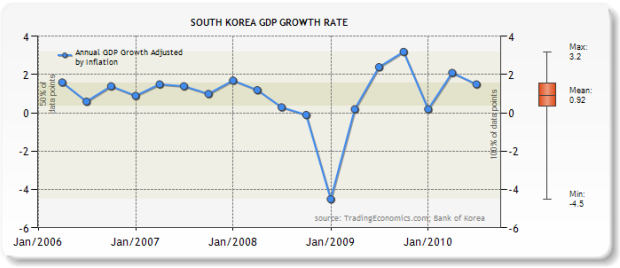
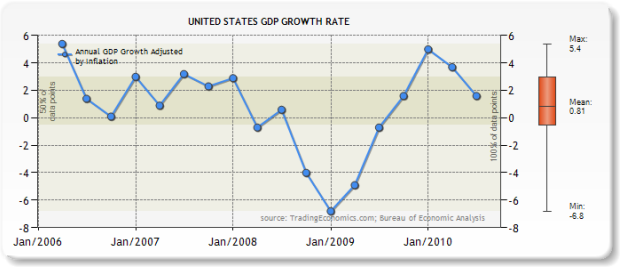
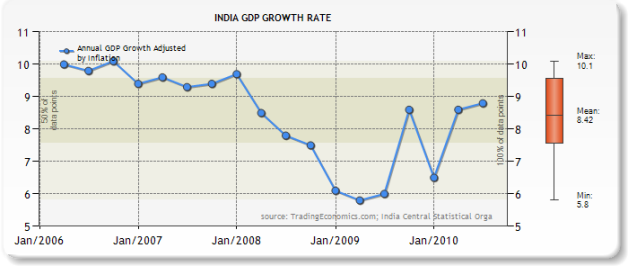
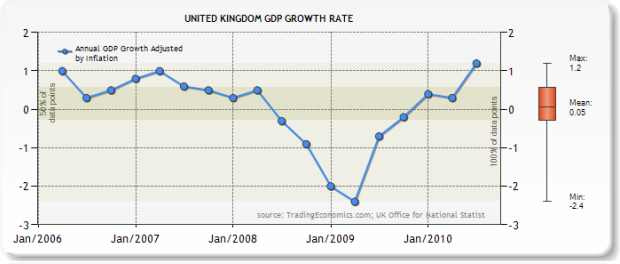
GDP Growth Rate Comparisons

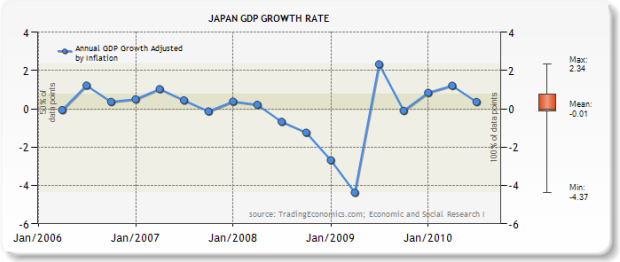






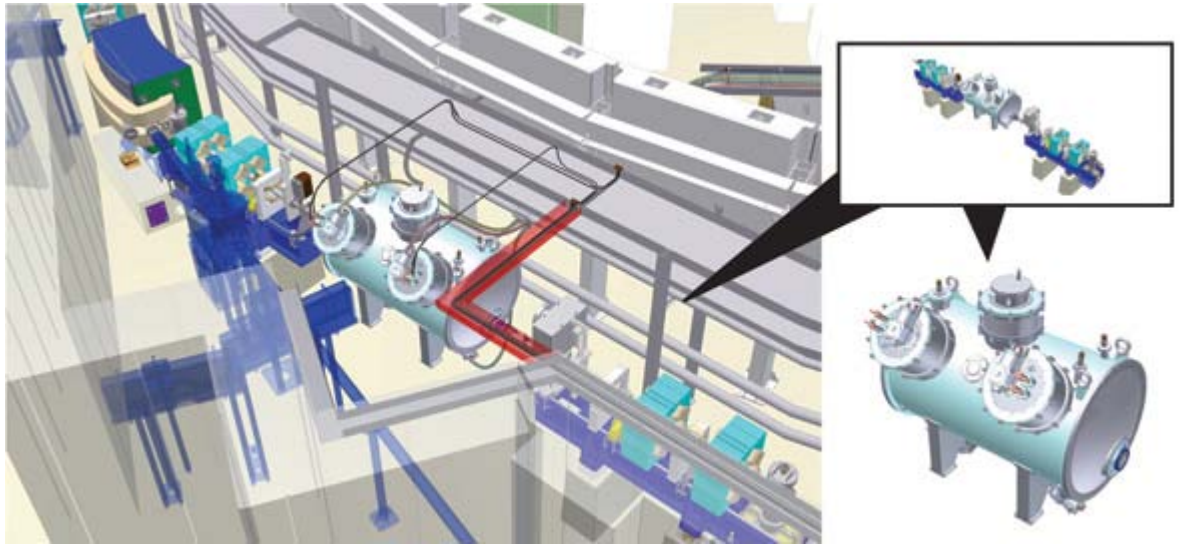


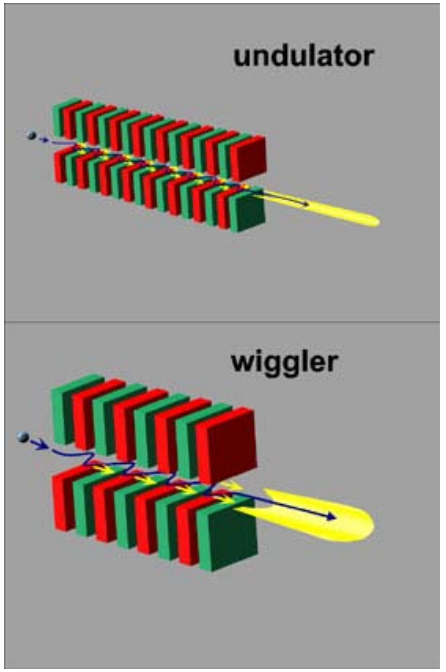




Budker Institute Novosibirsk Russia & 3GeV Light Source LNLS Campinas Brazil

Undulator magnets used in a storage ring to convert the electron-beam's energy into various electromagnetic radiation frequencies by creating a magnetic field of alternating polarity through which the free electrons are passed, causing them to "wiggle" and release radiation. Also known as a wiggler magnet enhance the output intensity by many orders of magnitude at e.g. Soleil in France or Diamond in UK





Sumitomo

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