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for

Greener, Healthier, Prosperous and Sustainable Future

Special Session

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WG4 Healthcare

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WG – Overview (1)

Magnetic Resonance Imaging (MRI)

- MRI is an extremely advanced imaging modality that has revolutionized the non-invasive medical diagnosis of diseases.
- MRI is the world's most widely used commercial application of superconductors.
- Moving to higher field MRI magnets will continue to expand the resolution and quantitative chemical studies in MRI.
- MRI researchers and manufacturers have investigated numerous approaches for improving the accessibility of MRI, including low-field MRI, specialty MRI, and low helium or no helium magnets.

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WG – Overview (2)

Particle Beam Radiotherapy (PBRT)

- PBRT is a type of cancer treatment that uses charged particles, like protons or heavy ions, instead of traditional X-rays.
  - The key advantage is its ability to deliver high doses of radiation directly to the tumor while minimizing damage to surrounding healthy tissues.
- The energy deposition pattern, known as the Bragg peak, releases most of the energy at a specific depth in the tissue, allowing for precise targeting of tumors that are difficult to reach with conventional X-rays, potentially improving treatment outcomes and reducing side effects.
- Useful for treating cancers in sensitive areas, such as the brain, spinal cord, or near vital organs, and for pediatric patients, where preserving healthy tissue is crucial.
- Superconducting magnets are critical to reducing the size of particle accelerators and beam guidance magnets, which allows for the design of highly compact and cost-effective treatment systems.

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Market Opportunities

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MRI

- The current market for MRI is approximately $5.3 Billion (2020) and is estimated to grow by $8.5 Billion by 2028 with a CAGR of 6%
- An aging global population contributes to a higher demand for diagnostic imaging, including MRI, as older individuals are more likely to experience health issues that require detailed imaging.
- Continuous improvements in MRI technology, such as higher resolution imaging, faster scanning times, and functional MRI (fMRI) for brain activity monitoring, expand the scope of MRI applications and attract investment in research and development.

Particle Beam Radiotherapy (PBRT)

- The Global Radiotherapy Market Size was valued at USD 6.78 Billion in 2022 growing at a CAGR of 7.3% from 2022 to 2032 and is expected to reach USD 13.72 Billion by 2032.
- Asia-Pacific is expected to grow higher during the forecast period.
- The increasing global incidence of cancer fuels demand for advanced and effective treatment options like particle beam radiotherapy, which offers precise targeting of tumors.

State of the Art

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MRI

- MRI is a well-established medical diagnostic tool used primarily at 1.5T and 3T. It is critical to modern medicine to diagnose disease in soft tissue.
  - High-field, high-resolution MRI is being used to study and understand the brain and diseases of the nervous system, such as Alzheimer's, dementia, PTSD, and ALS.
- Recently, the Iseult project at CEA Saclay began imaging at 11.7T, the world's highest field MRI system, with another 11.75 T system approved by the NHS in the UK to be installed at the University of Nottingham.
- A 14 T system is being developed at Raboud University in the Netherlands.
- All manufacturers have low-helium quantity solutions, and current trends are to seek cryogen-free solutions, for which HTS seems well-suited.

Particle Beam Radiotherapy (PBRT)

- Proton radiotherapy uses cyclotrons while carbon systems use synchrotrons.
- All recent proton systems use superconducting cyclotrons to reduce size and operating costs.
- The most recent focus is to develop single-room treatment systems compact enough to fit in traditional X-ray-based system vaults.

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TRL

MRI

- 1.5 T and 3.0 T systems are fully commercial products at TRL 9.
- The U. of Nottingham 11.75 T system is at TRL 5.
- There are a few 14 T systems being developed at TRL 2-3.

PBRT

- Superconducting cyclotrons for 250 MeV/amu protons are at TRL 9, i.e., they are commercially available and operating at several dozen sites worldwide.
- Most use NbTi with one system using Nb_3Sn.
- IBA and Normandy Hadrontherapy (NHa) are developing a 400 MeV/amu carbon superconducting cyclotron at TRL 8.

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WP4- Healthcare – Grand challenges and Strategic Roadmap

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WG Theme Ambition	4 years	7 Years	10 Years
• Can MRI become ubiquitous for diagnostic imaging? MRI in remote locations with remote diagnosis	Potential for demonstrators with investment	Complete studies in developed world clinical environment	Product deployed globally
• How can advanced NMR accelerate drug discovery and personalized medicine?	Access to high field NMR 1GHz or above – expand number of systems – how to form a consortium to make it a facility for treatment	Clinical trials progressing	Personalized medicine – diagnosis of disease, personalized drug therapy
• Ultra-High Field MRI	1^{st} images at Iseult, initiation of various 11.7 and 14 T development programs	More 11.7 T systems deployed. Statement on the feasibility of >14-16T designs. Roadmap for 20 T systems mapped out	More systems being started at 14T and above (cryogenics plant)
• MRI	NbTi, Nb3Sn, MgB2 Present performance of these conductors is sufficient for applications. Emergence of HTS and cryogen-free systems. Push on cryocoolers	HTS (reliable, quality, length over 1 km, joints), NbTi, Nb3Sn, MgB2 Increased performance at reduced cost desirable achievable for all HTS conductors. Higher perf. Cryocoolers	Fe based? , HTS, NbTi, Nb3Sn, MgB2 Phasing out of cryogen-dependent systems

NASEM report – High Mag II

Key Recommendation 2: The National Science Foundation, Department of Energy, and National Institutes of Health should develop collaborative programs to accelerate the development of high-temperature superconductor (HTS) magnet technology to support development in high-field magnetic resonance imaging, nuclear magnetic resonance spectroscopy, fusion, and accelerator magnets. For example, a large-bore solenoid (900mm+), high-field (14 T+) magnet demonstrator employing HTS technologies, ideally with ramp capability (5-10 T/s), should be commissioned to develop the foundational design method and wire technology that has potential applications across high-magnetic-field science.

Key Recommendation 11: Funding agencies supporting basic biological and medical research, such as the National Science Foundation, National Institutes of Health (NIH), and Department of Defense, whose constituencies are interested in ultrahigh-field magnetic resonance imaging (MRI), should consider a joint funding avenue for enabling the United States to implement human MRI at 14 T+, with NIH taking the lead.

Key Recommendation 10: The National Institutes of Health and National Science Foundation should also launch the development of a ≥28 T small animal magnetic resonance imaging (MRI) system based on combined low-temperature superconductor/high-temperature superconductor inserts, which in addition to opening new scientific frontiers would serve as the future human-size, ultrahigh-field MRI platforms. Notice that as similar platforms that serve small rodent MRI and Fourier transform-ion cyclotron resonance experiments in both homogeneity and bore demands, this system would simultaneously push the frontiers of this important analytical technique.

Requirements from Superconducting Materials

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MRI

- To date, all MRI systems from 1.5 T to 11.7 T use NbTi, which is commercially available.
- Systems beyond 11.7 T will need Nb_3Sn and perhaps HTS.
- Zero-helium systems will benefit from high-quality HTS materials but require substantial cost reduction for large-scale commercial feasibility.

PBRT

- Conventional NbTi and Nb_3Sn are adequate for future needs for advanced accelerator designs.
- Innovative technical and economic improvements could be made using (HTS) conductor technologies (REBCO, BSCCO, MgB2).
  - Most likely for gantry magnets or wound spiral pole tips for isochronous type cyclotrons.
  - This will require Improved performance at reduced cost for commercial feasibility.

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Potential Partnerships and Consortia

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MRI

- The MRI community has a strong society that is devoted both to the development of technologies related to MRI and the clinical implementation and outcomes of MRI, the International Society for Magnetic Resonance in Medicine (ISMRM) (https://www.ismrm.org/).
- This organization hosts numerous conferences and workshops to advance the state of the art in MRI.
- The National Institute of Health (NIH) in the US is heavily involved in developing next-generation medical technologies, and the National Institute of Biomedical Imaging and Biomedical Engineering (NIBIB) has been and will be a critical partner in the development of advanced high-field MRI and ubiquitous MRI.
- The National Health Service (NHS) in the UK is supporting development of very high field systems while CEA in France supports the development of a carbon beam RT system.

PBRT

- Several international organizations that support research, development, and expanded availability for hadron therapy treatments:
  - Particle Therapy Co-Operative Group (PTCOG) (https://www.ptcog.site/)
  - The European Network for Light Ion Hadron Therapy (ENLIGHT) (https://enlight.web.cern.ch)
  - NGOs that sponsor R&D in hadron therapy, such as NIH (US), NHS (UK), NIRS (Japan)

Impact summary

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MRI

- The first 40 years of MRI development have eliminated the need for exploratory surgery and enabled the diagnosis, planning, and treatment of numerous diseases, leading to better outcomes and health.
- The continued development of MRI will improve medical outcomes through better diagnostic imaging, treatment, planning, and therapy.
- Improvements in access to MRI and NMR will enable the diagnosis and treatment of disease in areas where this is currently not possible. This will aid in reducing inequalities in healthcare and quality of life

PBRT

- While the upfront cost may currently be higher, considering outcomes, toxicities, and hospitalization rates after radiotherapy, the overall value of proton therapy will be better than photon therapy for certain types of cancer.
- The most immediate impact will be seen in children with improved outcomes and near elimination of risk of developing secondary cancer.
- The much wider availability and dissemination of particle therapy systems will profoundly impact improved cancer care worldwide.

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Call to Action

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- Follow up on the NASEM High Mag II report with community workshops on how to best proceed with 14T and 28T development.
- Focus on how to increase access to MRI globally.
- Focus on how to increase access to proton beam therapy.

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