PUBLISHABLE SUMMARY

ENHANCED EUROPEAN COORDINATION FOR ACCELERATOR RESEARCH & DEVELOPMENT

The EuCARD-2 collaborative project for particle accelerator R&D has completed its third year progressing towards its scientific objectives, strengthening the collaboration via a large number of general and topical workshops, and fostering collaboration with industry.

The Catalysing Innovation Network organised two successful “EuCARD-2 meets industry” events centred on the key topics for the application of EuCARD-2 technologies to society identified during the first part of the project: the production of medical radioisotopes with accelerators and the development of new materials for extreme thermal management. The workshop on medical isotopes took place at the Cockcroft Institute (UK), and brought together industry, clinicians and academia to explore the applications of accelerator technologies for future medical isotope production needs. After highlighting the expected increase in future demand for medical isotopes in diagnostics and targeted radiotherapy, the workshop reviewed various production options and initiated joint collaborative projects to address the shortages in future radioisotope supply. The second topic was the subject of a workshop on applications of thermal management materials that was held at CERN. This workshop explored how novel thermal management materials required for the future generation of accelerators can be applied to industrial domains such as automotive, aerospace, electronic packaging, fusion and solar energy. The state of the art of novel thermal management materials was reviewed, new applications for these materials were identified, and new industrial and academic collaborative R&D projects were initiated.

The Network on improving Energy Efficiency promoted the design of novel Radio-Frequency devices to more efficiently generate the large microwave fields required for particle acceleration. The options include multi-gap klystrons, multi beam inductive output tubes or magnetrons with improved phase stabilization. For the overall energy management of large research infrastructure schemes for dynamic adaptation to the situation on the grid were proposed and analysed.

Besides its contribution to the radioisotope Workshop, the Network on the Applications of Accelerators explored a large number of applications of electron beams of less than 10 MeV in industry and the environment, like new methodologies for the removal of emerging and refractory contaminants from water and wastewater. A particular interest, but also a particular challenge, is the use of this technology in the developing world, where existing water treatment techniques can be very limited.

The exploratory Network on Extreme Beams has organized or co-organized fourteen workshops addressing fundamental topics for future machines. These included the preparation of optics measurement, diagnostics, and correction tools for the future operation of the Large Hadron Collider at CERN; space-charge effects relevant for high-intensity proton storage rings, future colliders, boson factories (Higgs and Z) and future lepton-hadron colliders; the design of electrostatic
storage rings for precision measurements of the electric dipole moment of the electron; and the development of low-level radio-frequency systems for intense proton linacs like the European Spallation Source in construction at Lund (Sweden).

The Low-emittance Rings Network, which federates the efforts of synchrotron light sources and advanced electron rings for particle physics towards achieving extremely small beam size (emittance), has registered important results and has identified some critical points for future investigation. These include lattice design, the use of damping wigglers, multi-objective optimisation methods, flexibility of ring design, symmetry and periodicity of the ring, choice of working point, injection and extraction, and straight section length for insertion devices.

The Network on laser-based Novel Acceleration Techniques has produced the proposal for a Design Study aimed at the construction of a pilot plasma wakefield acceleration facility. The proposal was submitted under the Horizon 2020 programme and, following a positive evaluation, the Study was initiated in November 2015. The second European Advanced Accelerator Concepts (EAAC) workshop took place in 2015 and continued a series initiated as part of EuCARD-2 with the goal of creating a European forum for new accelerator technologies. At this second edition, the EAAC registered a major success, with 258 participants, up by 78% from the 145 of the first Workshop in 2013, from 23 countries. Particularly encouraging was the participation of more than 50 students, indicating how this challenging field of research may be of interest to younger generations. Among the new acceleration techniques analysed at the EAAC and at the Network events were the recent advances in dielectric laser acceleration: the excitation in dielectrics of near-field modes at nanograting could provide accelerating gradients up to 3 GeV/m, about 30 times the present state-of-the-art for conventional accelerators. This technology is now on the edge of a major improvement using a variety of structures to achieve efficient coupling of the laser; major research programs were recently started in Europe and worldwide.

The three Transnational Access facilities of EuCARD-2 have steadily provided access to a large number of user groups coming from different European countries. The Ion Cooling Test Facility of STFC (UK) has so far provided access to 21 users and delivered 3122 units of access for the full project period, which already exceeds the number of offered units for the duration of the project. For the current reporting period, 1772 units of access have been delivered to 16 users. The HiRadMat facility at the CERN SPS accelerator provided beam to five experiments with a total of 1520 access hours. The MagNet superconducting magnet test stand at CERN expanded its reach towards testing of instrumentations at cryogenic temperature; six experiments were performed during the reference period, including users from 5 different countries and 10 different universities, who have produced a large number of scientific articles. Already 80% of the offered access was provided in good coordination with the tight schedule of CERN base programmes.
The Joint Research Activity devoted to the development of the future generation of **accelerator magnets based on High-Temperature Superconductor** (HTS) technology successfully assembled a large number of suitable lengths of high-performance 12 mm tape, making use of the 250 m of high-quality YBCO-type HTS tape produced within the project. Additionally, various worldwide manufacturers have procured 1 km of tape that will be compared with the EuCARD-2 tape performance. The production of the special Roebel-type cable needed for the HTS magnets was tested using dummies made of strips of steel tape, used for winding trials and mechanical tests; two cable geometries with different cable thickness have been defined. An alternative manufacturing procedure for Roebel cables has been introduced, where tapes are punched right after the silver cap layer deposition, and copper is electroplated in meandered geometry. Multi-physics software has been developed to compute the dynamics of the Roebel cable. Progress has also been made concerning the quench protection system; a subscale coil (“Feather0”) has been wound and will be used to test assembly techniques and quench detection efficiency. The magnetic and mechanical designs are well advanced for the baseline magnet design (aligned block) as well as for two alternatives (cos theta and to a lesser extent the stacked tapes). Tooling for coil winding as well as coil impregnation has been completed for the two first designs.

The Joint Research Activity developing **Materials for fast High-density Energy Deposition** reached an important goal in the second EuCARD-2 period, validating Molybdenum Carbide – Graphite (MoGr) and Copper-Diamond (CuCD) composites as robust materials for the upgrade of the LHC accelerator. These materials can withstand beam impacts equivalent to accident scenarios relative to injection error and asynchronous beam dump, as tested in the HiRadMat facility. Another achievement was the production of new material grades to improve performance against irradiation and high-energy deposition. Improvements were obtained by optimising the composition and fibre content, increasing the annealing temperature to enhance the release of internal stresses, and adding a tiny quantity of Titanium. Measurements on these new grades showed a significantly reduced radiation-induced deformation with respect to previous samples.

The Joint Research Activity on the development of **Innovative Radio-Frequency Technologies** has progressed in many directions. New deposition processes for the preparation of thin superconducting films have been demonstrated; the qualification infrastructure have been enhanced and first elliptical cavity tests are now underway with the expectation of achieving breakthrough gradient and quality factor performance before the end of the programme. Normal conducting, high gradient X-band technology is becoming more widespread for a variety of accelerator applications and advances have been made in wakefield monitors which provide precise alignment information in order to minimise emittance dilution in FEL facilities as the SwissFEL at PSI (CH). X-band crab cavities have been
fundamentally validated in terms of both gradient and phase synchronisation performance, with achievable breakdown capability way above that required for CLIC. Industrial development of X-band technology has also advanced through the successful development of a new high efficiency klystron-type RF power source, the kladistron ("quasi-adiabatic klystron"), a design that has already obtained the interest of a major European klystron manufacturer. A practical demonstrator is now being prepared by modifying an existing klystron. For the benefit of the European X-FEL project at DESY, complex simulation processes have been determined and validated which enable large cavity string analysis to be performed rapidly with a very high level of detail and accuracy, thus safeguarding against problematic higher order modes. New HOM detection electronics has also been manufactured and tested which allows the HOMs within the 3rd harmonic RF system to be used to provide high precision beam diagnostics to control the beam delivery to very high precision. Finally, advanced material photo-cathodes have been developed and analysed for both normal conducting and superconducting RF gun implementation achieving high Quantum Efficiencies and low intrinsic emittances. Such cathodes are being qualified using new characterisation facilities in the partner institutes of EuCARD-2.

The Joint Research Activity on experimental validation of Novel Acceleration Techniques concentrated its activities on the production of high quality and stable electron beams in a laser plasma accelerator; an interesting technique consists in the interaction of a single laser pulse with the sharp density gradient produced by placing a blade in the path of a supersonic gas jet. This approach was used to demonstrate control of the electron energy and in a dedicated experiment a small jet was injected at 90 degrees to a longer gas jet. In addition to improving the stability, this scheme also allows precise control of the electron beam charge and peak energy. A first achievement towards Laser Wakefield Acceleration with external injection was reached at INFN where electron beams with the required parameters, charge as low as 20 pC and rms lengths down to 6 µm (20 fs duration), have been produced and measured. This method was applied not only with one single electron bunch, but also for the controlled compression of a sequence of pulses. In the field of high-gradient acceleration in a plasma excited by a proton beam, preparation for the crucial AWAKE experiment at CERN has progressed with the construction and installation of the prototype plasma cell. The baseline cell is a rubidium (Rb) vapour source ionized by a laser pulse, with challenging requirements.

**Coordinator:** CERN

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