the production of such an element, or of other radioelements used in medical imaging, diagnostics, and therapy. As a result, CERN took a patent [49] on the TARC idea, and various industrial pharmaceutical companies showed interest in its exploitation. The patent, valid until 2017, is very much of interest, as the demand for $^{99m}$Tc has exploded and new therapies based on lutetium, rhenium, holmium, etc. are in rapid development.

The TARC experiment was a landmark experiment, which studied the phenomenology of neutrons in lead. It showed that ADS may be used to destroy nuclear waste and provide an alternative to nuclear reactors in the production of radioisotopes. It validated an innovative simulation that is now used for the design of ADS. The TARC concept also led to the design and construction of the CERN neutron Time-Of-Flight facility, n_TOF [Highlight 3.9], with its high rate, high precision neutron flux and low background. It offers unique conditions for the measurement of neutron cross-sections, a necessary input to any reliable simulation and development of new nuclear systems.

## 10.7 A CLOUD Chamber with a Silvery Lining

Jasper Kirkby

During his first visit to the Ben Nevis Observatory in 1894, the future Nobel laureate C.T.R. Wilson became fascinated by clouds and the beauty of coronas and “glories” (coloured rings surrounding shadows cast on clouds). He returned to the Cavendish Laboratory in Cambridge determined to re-create clouds in the laboratory and study their physical phenomena. This led him to develop the expansion cloud chamber — a detector on which much of the experimental foundation of particle physics was built in the first half of the 20th century.

More than a hundred years later, a new cloud chamber is in operation at CERN. The CLOUD experiment is optimized to study the influence of cosmic rays on aerosols and clouds [50]. CLOUD reproduces atmospheric conditions in a large chamber (Fig. 10.10) to study aerosol particle formation and growth in controlled laboratory conditions. Clouds are generated by adiabatic pressure reductions of humid air parcels, as in Wilson’s cloud chamber, but at the much smaller water vapour supersaturations found in natural clouds (a few times 0.1%, compared with around 500% for a Wilson cloud chamber). Depending on the air temperature and the nature of the seed particles, either liquid or ice clouds form.

The primary scientific goal of CLOUD is to answer the question of whether or not cosmic rays exert a climatically significant effect on aerosols and clouds, as suggested by satellite observations first reported in 1997 [51]. This intriguing

Fig. 10.10. Fisheye view vertically upwards inside the 3 m CERN CLOUD chamber. The inner surface of the stainless steel chamber is electro-polished to reduce retention of contaminants. An array of 265 fused silica fibre-optic feedthroughs is installed on the roof of the chamber to provide a uniform column of UV light for simulating atmospheric photolytic chemistry. A pair of magnetically-coupled stainless steel fans (not shown) mounted on the upper and lower manhole covers ensure mixing of the air, trace gases, ions and aerosol particles inside the chamber. Fast response (< 1 s) thermometer strings (not shown) measure the air temperature, which can be adjusted between −70°C and +100°C by a precise thermally-controlled environment. Two transparent high voltage electrodes, supported on partially-conducting ceramic rods, provide an electric field of up to 20 kV/m to clear ions from the chamber for ion-free experiments. Sampling probes (not shown) are inserted through a ring of DN100 ports seen in the mid plane of the chamber. These are connected externally to state-of-art instruments such as mass spectrometers that continuously analyse the contents of the chamber during experimental measurements. The configuration of analysing instruments is modified for each experimental run according to the scientific goals.

possibility could shed new light on the long-sought mechanism for solar-climate variability in the pristine pre-industrial climate [52, 53]. Atmospheric aerosols and their effect on clouds are recognized by the Intergovernmental Panel on Climate Change [54] as the largest source of uncertainty in anthropogenic radiative forcing. A second scientific goal of CLOUD is therefore to quantify the fundamental physico-chemical processes controlling aerosol particle formation and growth in the atmosphere, and thereby help to reduce the current uncertainty in Earth's climate sensitivity and sharpen global temperature projections for the 21st century.

CLOUD is the first — and so far only — experiment to reach the demanding technological performance required to study these processes under atmospheric conditions in the laboratory. Extraordinary care has been paid in the design and construction of the CLOUD chamber and its associated systems — gas, thermal, UV and electric field — to suppress contaminants at the technological limit. CLOUD experiments have shown that atmospheric nucleation and growth is driven by atmospheric vapours that are present in minute amounts of only a few parts-per-trillion by volume (pptv). The key vapours comprise sulphuric acid, ammonia, amines and highly oxidized biogenic molecules originating from trees [55-59]. Ions from galactic cosmic rays and natural radioactivity play an important role in the formation of aerosol particles under certain conditions (Fig. 10.11), although evaluating their climatic significance requires further measurements.

Why CERN? First, the CERN PS provides an artificial, adjustable source of "cosmic rays" that reproduces, in a chamber, ion concentrations found between ground level and the lower stratosphere. Second, the unrivalled technical performance of the chamber and its associated systems is the result of a great deal of CERN expertise. Finally, there is an important cultural "trading zone" between scientific disciplines. CLOUD is a "general purpose" detector that measures every aspect of the physical process under study. Although familiar to high energy physics, pooling the resources of a large collaboration in this way and building a single, integrated high-performance detector is new to atmospheric science.

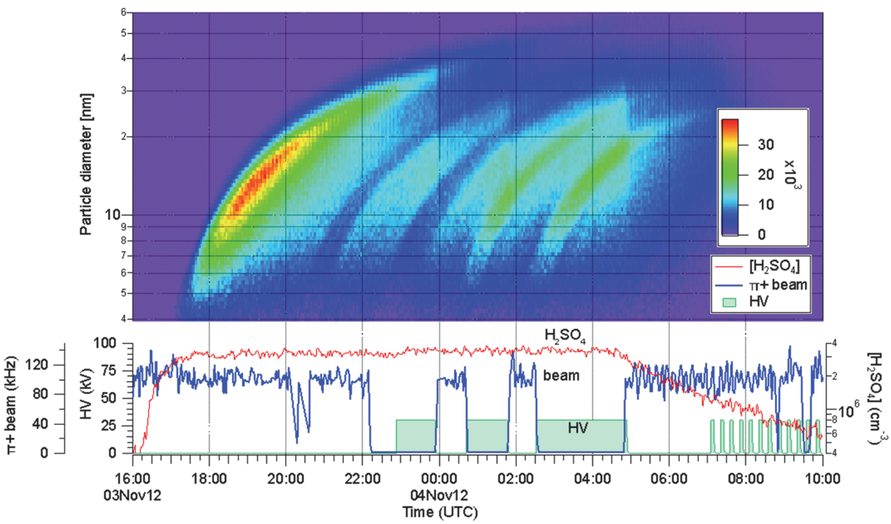


Fig. 10.11. Formation of new aerosol particles from trace atmospheric vapours in CLOUD (upper panel). The aerosol particles grow in size (vertical axis) by condensation over a period of several hours (horizontal axis), reaching sizes sufficient to seed cloud droplets. The characteristic "banana" shapes show fresh bursts of particles that form during periods of high ionization in the chamber due to the $\pi^+$ beam from the CERN PS and the absence of an electric clearing field. In this case the trace gases included 0.15 pptv sulphuric acid and oxidized biogenic vapours. The lower panel shows the $\pi^+$ beam intensity (blue line), the clearing field (green blocks) and the amount of sulphuric acid (red line).

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