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The Dismantling Project for the Large Electron Positron (LEP) Collider

J. Poole

Abstract

The LEP accelerator was installed in a circular tunnel 27 km in length with nine access points distributed around the circumference in the countryside and villages which surround CERN’s sites. The dismantling project involved the removal in less than 15 months of around 29000 tonnes of equipment from the accelerator itself and a further 10000 tonnes from the four experiments - all of which were located at an average depth of 100 m below ground level. There was no contamination risk in the project and less than 3% of the materials removed were classified as radioactive. However, the materials which were classified as radioactive have to be temporarily stored and they consume considerable resources.

The major difficulties for the project were in the establishment of the theoretical radiological zoning, implementation of the traceability systems and making appropriate radiation measurements to confirm the zoning. The absence of detailed guidelines from the French authorities, having no threshold levels for release of radioactive materials and being the first dismantling project of a large accelerator made the task more difficult and more expensive. Further difficulties remain because materials classified as having very weak radioactivity (très faiblement actif -TFA) by the zoning study which have no induced activity have to be treated in the same way as radioactive waste. This paper describes the organisation of the project and its execution and examines some of the problems which arise from the INB system; the radiation protection aspects of the project are discussed in the paper entitled “Déclassement du grand collisionneur d’electrons/positrons (LEP) du CERN”, also presented at this conference.

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1. Introduction

1.1 Objectives

The construction of the Large Hadron Collider (LHC) requires that the tunnel is cleared of all LEP equipment and services which are not needed for the new machine. The tunnel will then be made available for civil engineering and installation of the new machine within the time constraints determined by the LHC Project. The LEP Dismantling Project concerned all of the work involved in removing the equipment from the tunnel and its subsequent storage/disposal. In addition to the removal of the equipment the project involved the planning of the work (including logistics of transport) and construction of such new facilities/equipment as were necessary.

1.2 Internal Constraints

The equipment to be removed was located within the tunnel and in the parts of the machine which extend into the experimental areas. The boundaries between LEP equipment and the experiments were set at, or very close to, the beam tube. The removal of the experimental detectors was the responsibility of other projects (one per experiment).

The planning and logistics was made in accordance with the LHC construction programme and by the planning group in CERN-AC. The major factors affecting the project were the requirements of the civil engineering and the installation schedule for the LHC general services. At several locations in the tunnel it was necessary to enlarge the tunnel and even excavate new caverns and the civil engineers needed exclusive occupancy of parts of the tunnel for these works. In the initial schedule it was planned to deliver 60% of the tunnel to the civil engineers after only 55 days of dismantling. Fortunately, the civil engineering schedule was modified and this allowed a relaxation of the dismantling activities.

CERN's position as an international organisation also had an impact on many aspects of the dismantling because in addition to the French regulations, we have to respect a number of international agreements and because CERN spans the international border between France and Switzerland, there are complex customs issues. Finally the four LEP experiments were run by separate international collaborations who had not signed the convention with France making LEP an INB.

1.3 External Constraints

Because LEP was classified as an INB, a safety plan had to be established and agreed with the French authorities before work could start and all of the work had to be carried out according to these specifications. Within this documentation were detailed descriptions of the necessary procedures and preparations to meet the requirements for general and radiological safety, radiological zoning and traceability of the materials removed.

2. Project Description

2.1 The Accelerator

(a) Regular arc with sextupole/quadrupole assembly in the foreground

(b) Straight section with monorail train

Figure 1 The LEP Tunnel

The LEP accelerator was formed of eight arcs with a bending radius of ~3500 m with a total circumferential length of around 19 km, separated by eight straight sections which were approximately 1 km long centred on the crossing points. The beams passed within the continuous 27 km long vacuum chamber, guided and focused by powerful electromagnets. The arcs were formed of a regularly repeating structure about 40 m long containing dipole, quadrupole, sextupole and orbit correction magnets. The arc dipoles account for approximately 50% of the weight of equipment of the accelerator. The straight sections contained focusing and correction magnets as well as the accelerating systems, injection systems, electrostatic separators, collimators, beam instrumentation and the beam dump system. Running alongside the accelerator itself between it and the tunnel wall are the services comprising cooling water, electrical cables and bus bars and so on, some of which can be seen in Figures 1, 2 and 3. The four experiments were built around the collision points and spaced equidistantly around the circumference and the beams were separated at the other four crossing points.

LEP was operated by accelerating the beams through a chain of injectors and accumulating them at 22 GeV in the main ring and once sufficient intensity was available, the beams were accelerated to the operating energy and brought into collision. LEP1 (1989-1995) provided colliding beams of electrons and positrons with energies around 45 GeV to study the physics of the Z particle. The accelerator was then upgraded to provide beams of up to 100 GeV (LEP2) to study the physics in the region of the production of W particles.

Accelerating energy was supplied through high power radiofrequency (RF) cavities which were installed in the straight sections on either side of the experiments. For LEP2 the copper RF cavities were supplemented by 72 superconducting cavity modules (see Figure 2).

The basic concept for dismantling was to have teams advancing through the tunnel, one behind the other, progressively removing the various components. The problem of removal of the dipole magnets was one of the first to be studied. At the time of installation, the 10 t magnet assemblies were lowered through one particular shaft which would allow the 11.4 m assembly to pass. Since it would not be possible to remove them in this way within the time available, the only route for the removal of these elements involved lifting them from an average depth of 100m through a shaft measuring <6m wide. It was therefore necessary to cut the vacuum chamber and excitation bars between the two cores which made up the assembly and to place one half on top of the other for evacuation.

In order to avoid dust a hydraulic nibbler (Figure 3) was chosen to cut through these elements which measure up to 90 mm square. For similar reasons it was specified that the pipe work from the cooling pipes should be cut using circular pipe cutters and the cables and busbars were cut using hydraulic scissors. Most of the other equipment, including the quadrupoles, sextupoles, vacuum equipment etc. was removed by un-bolting it and lifting it out.

Figure 2 Superconducting RF System Cavity Module

Figure 3 Cutting the dipole magnet excitation bars with a hydraulic nibbler

In the remaining 8 km of the tunnel, the major component was the RF system, interspersed with magnets, electrostatic separators and instrumentation. In general, the straight sections contained most of the radioactive materials although there was also some activity in the region of the injection and the beam dump.

2.2 Evolution

In Spring 1998 the first meeting of the 'Transformation of LEP' working group was held and several introductory presentations on the theme of dismantling an INB were made. In the following months the working group identified the external constraints mentioned above and it also identified the equipment and materials to be removed.

During the last quarter of 1998, CERN management realised that substantial resources were required for the production of the documentation and for the preparations of the execution.

There were many technical problems for dismantling LEP such as the problem of removing the 1600 dipole magnets. The working group studied a large number of such technical problems and found individual solutions to most of them but by the start of 1999 there was still not a global view of the project. At this time a new committee was formed from about 30 senior engineers representing all of the groups involved and it was given to mandate to define the overall strategy and to organise the preliminary stages of the dismantling. This committee completed its mandate and handed over to a second committee of about 30 people which was charged with the coordination of the execution phase.

2.3 Structure

The activities of the project can be grouped under the following main headings:

- Preparatory phase
- Studies and documentation
- Tendering and procurement
- Planning
- Infrastructure
- Traceability, radio-protection, recycling
- Security and storage
- Execution
- Safety, training, cutting, transport, coordination and follow up

Each activity was broken down into its components and a total of more than 150 different activities requiring more than one man-month of effort were identified.

2.4 Early Phases

Initially, the main efforts were focused on the preparation of the documentation for DSIN and finding solutions to technical problems. The bulk of the documentation activities were concentrated on the radiological zoning where lengthy simulations were required together with an experimental programme aimed at their verification. These activities are dealt with in detail in the other paper concerning LEP Dismantling which is presented at this conference [1] and only a brief overview is given here. A team of experts in equipment, services and safety groups were asked to prepare sections of the documentation.

There were three channels through which LEP components could become radioactive: from distributed beam losses around the ring, from localised losses where components intercepted the beam and from electron sources in the superconducting RF cavities. Activation from synchrotron radiation was shown to be insignificant. In order to establish the radiological zoning one needs to know the quantities and parameters concerning the interaction of the beams with the surrounding matter. When the particles interact with the surrounding matter in a high energy lepton accelerator like LEP they induce electromagnetic cascades and have very little interaction with the nuclei. As a result of this LEP was a rather 'clean' machine in nuclear terms with only some localised pockets of induced activity.

In order to predict the induced activity it is necessary to know how much beam interacted with the surroundings, the beam energy and the chemical composition of the material struck by the beam. Unfortunately these parameters were not known exactly – the operating conditions of the accelerator were constantly changing during its lifetime and beam losses were not always localised. Clearly most of the beam would be extracted to the beam dump, but this was not installed in the early years of operation and sometimes the beam was lost at random. The understanding of the physics of the beams enabled beam losses and activation to be predicted on a statistical basis and this was backed up by a long series of experiments and measurements during the final years of operation. Given the size of the accelerator it was not possible to run the simulation programs for each m length of the 27 km and therefore fine resolution was only utilised where anomalies were discovered during the dismantling. In spite of this simplified approach, around 7 man-years were spent in the preparation of the radiological zoning report.

It was necessary to create a traceability system [2] that could handle the quantities involved, there were tests made on the durability of barcode stickers and various hardware systems were evaluated. It was decided that the trace information should be recorded in the corporate database (Oracle) and a reader system directly connected to the database was designed and tested.

The CERN procurement system requires announcement of major contracts about one year ahead of their placement and for LEP Dismantling it was necessary to place new contracts for sales of scrap, radiation protection activities, cutting and removal of pipe work and electrical infrastructure, the weigh bridge and radiation monitor, security patrols and so on. The main difficulty in this respect was being able to write accurate detailed technical specifications for activities which were still in the process of definition. Existing industrial services contracts were used extensively during the dismantling, the major one being for handling and transport which corresponded to about 30% of the total project cost.

The planning for the project was prepared within the framework of the overall planning for the LHC machine by the specialist group dedicated to this task. The schedule was mostly constrained by the requirements to deliver certain parts of the tunnel at dates fixed by the civil engineering contracts and by the capacity of the cranes. Large or heavy equipment could only be removed from the tunnel using the overhead cranes located above access shafts which measure 5.75m × 1.75m. The six cranes available had a maximum capacity of ~10 tonnes and it takes between 30 and 45 minutes to lift one load. Given these constraints it was possible to establish a programme working 8 hours per day during weekdays only which met the requirements for delivery of the empty tunnel to the civil engineers. The contingency in this plan was the possibility to work two shifts and/or weekends.

2.5 Infrastructure

Once the technical decisions had been taken, it was possible to start construction of the infrastructure – modifications to the tunnel to allow passage of equipment, re-routing of communications and services, containers, storage areas and so on.

The civil engineering works required a complete removal of all equipment and services from those sections of the tunnel involved. The tunnel had always been used to house all of the services including electricity and hard-wired communications such as the alarm system. Alternative solutions had to be found for the alarms and these involved laying new fibre-optic links across several kilometres of the local countryside so that there was a surface network for the alarms. The electrical supply to each of the eight main access points was not affected because the power requirements were modest in comparison with the operational period and all points had a sufficient independent supply.

Several hundred people were expected to be working underground and provision had to be made for their health and safety. Barracks and sanitary equipment were installed and a number of oxygen masks were purchased to supplement the existing supplies.

More than half of the equipment (by weight) was removed from the tunnel as complete units in the same form as they had been installed but the remainder had to be transported in containers. Special 5m long containers were constructed to make optimum use of the dimensions of the access shaft and a large number of standard (1 tonne, volume about 700 dm^3) metal containers were ordered. The 5m containers were used for large items like cables and pipe work, whilst the others were used for items such as fittings, seals and bellows.

A major constraint was the lack of storage space because large volumes of equipment for the LHC were arriving at the same time as LEP equipment was coming out of the tunnel and several major storage related initiatives had to be launched for the project. Equipment from the tunnel had three types of destination – recycling, storage for re-use and radioactive waste. Almost half of the equipment was destined for re-cycling and a special loading area of around 4000 m^2 was created on the Prevessin site. This area was sufficiently large to buffer around two weeks worth of equipment coming from the tunnel.

Much of the equipment for re-use was of very high value and required storage in warm, dry areas. In order to find space, large quantities of old equipment were thrown away and the existing storage facilities were rationalised to liberate space. Around 12000 m^3 was liberated in the old ISR tunnel: 4000 m^3 of this was given over for radioactive waste from the SPS, 1000 m^3 for LEP radioactive waste, 1000 m^3 for radioactive equipment from LEP for re-use and 6000 m^3 for the non-active part of the LEP superconducting RF system. On the Prevessin site a surface area of a further 1500 m^2 was liberated in the SL storage areas in buildings 879 and 956, the latter being fitted with a dehumidifier to facilitate the storage of klystrons.

A large amount of refurbishment was necessary in the ISR tunnel in order to make it suitable for a storage area for radioactive waste. Once the basic structure was ready, racking was installed to receive the various equipments.

Equipment from the machine which had been sold for recycling was collected from the loading area on the Prevessin site and had to pass through a radiation monitor and weigh bridge. The radiation monitor and weigh bridge were new installations put in place for the dismantling. The materials from the four LEP experiments also had to pass through this monitoring and weighing system.

The transport of all of the materials coming from LEP required several extra vehicles including fork-lift trucks and heavy goods vehicles and it also relied heavily on the existing infrastructure – monorail and cranes. The existing infrastructure was therefore fully overhauled before the start of the project and the roads and access paths were improved or modified to facilitate the movement of vehicles.

Traceability stations were set up at the top and bottom of the crane/lift shafts as well as at the loading area at Prevessin and in all the main storage areas. These stations required the installation of internet connections, computers and data links to mobile barcode readers.

Since the dismantling of the experiments was carried out in four independent projects, a strict separation was enforced between them and the machine. This required the installation of fences and creation of specific entry/exit points on the LEP sites as well as the erection of many signposts and warning notices.

Personnel access to CERN facilities is through a series of concentric controls – from the outside one has to pass through a gate which is either manned or has a card reader and then for the normal underground areas through a card reader and turnstile which gives access to the lift. There are of course much more complex systems which ensure personnel safety as one comes closer to the hazardous areas but these were not involved in the dismantling. At the end of LEP operation for physics, the card reader system controlling access to the underground areas was only adequate for the infrequent use during normal operation and it was therefore necessary to upgrade the whole system to handle the large flux expected during dismantling. New readers were installed and the informatics system was upgraded to allow much more flexible management.

During the dismantling process large quantities of material were moved to surface areas at the remote LEP sites and additional security was implemented in order to avoid theft of materials coming from the INB. Unlike most INBs, CERN’s sites are set up in the style of a university campus with minimal access restrictions and during normal operation there is no permanent security presence on the remote sites. During dismantling the sites were guarded around the clock, seven days per week and there were also additional mobile patrols making random checks and inspections. During working hours the project was able to benefit from this extra presence and the security guards took on additional responsibilities concerning checks of people’s safety equipment and controlling access to the various areas.

2.6 Logistics

Figure 4 shows schematically the planning for dismantling in a typical section of the accelerator with time along one axis and distance around the tunnel on the other axis. The first two weeks are assigned for making the areas safe and then the first team comes in and opens the vacuum chamber and so on. The sequence of tasks for the dismantling teams was as follows:

- Make areas safe from the beam
- Detailed radiological survey to confirm ‘zonage’
- Make equipment safe in readiness for dismantling
- Remove radioactive elements
- Disconnect vacuum components
- Cut vacuum chamber and bus bars
- Remove beam line components (magnets, vac. chamber etc.)
- Remove cables
- Remove cooling pipes
- Clean up remaining small items
- Radiological survey and re-classification of zones

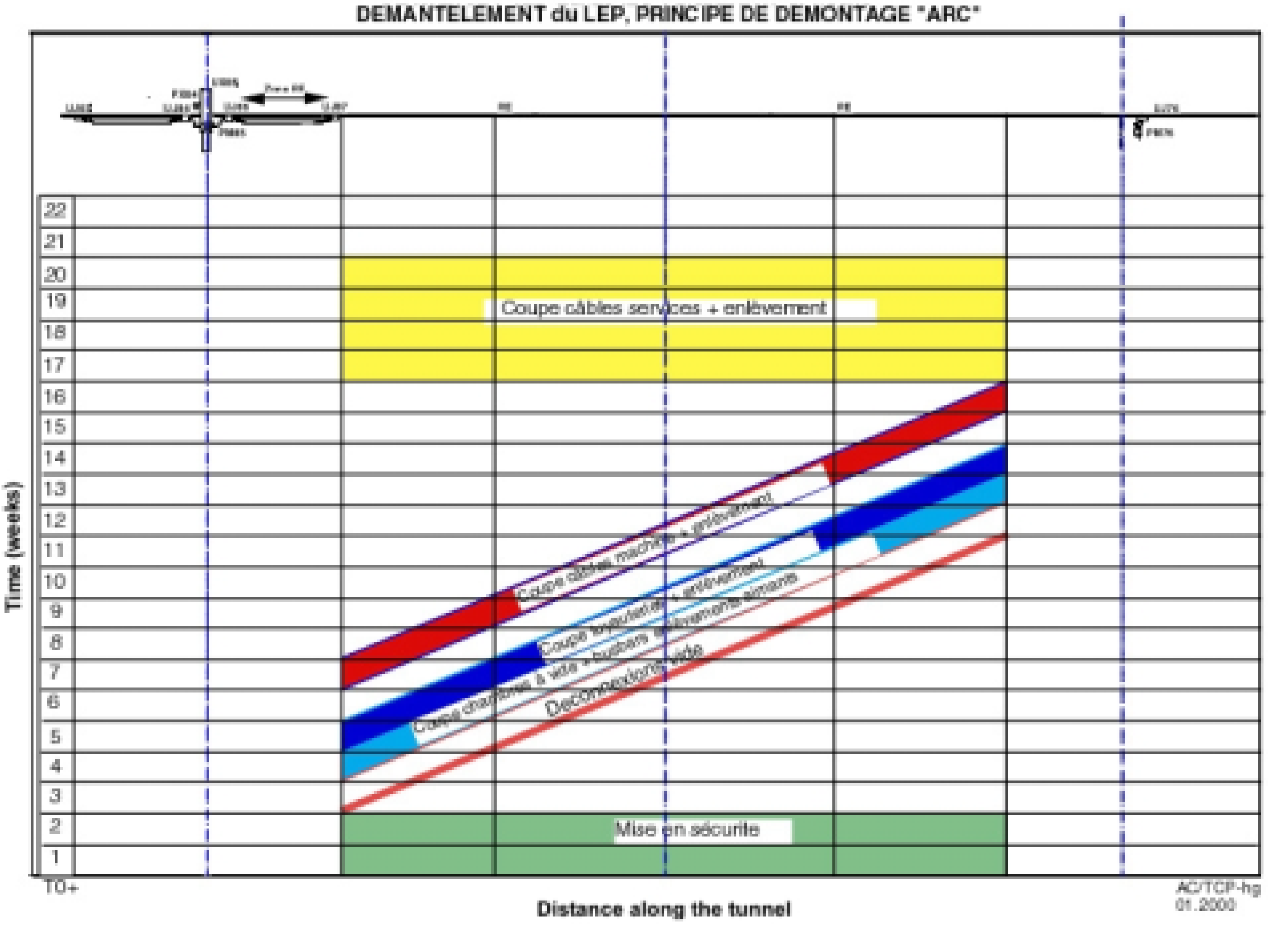

Figure 4 Dismantling in a LEP Arc

Once the last beam was dumped in LEP, the process of making areas safe was started – essentially this involved condemning beam transport equipment and installing physical obstacles in the beam path. Once this had been done, a detailed radiological survey of the whole accelerator tunnel was made in order to confirm the radiological zoning. The nuclear zones were identified and suitable panels and stickers were installed and then the process of making all the equipment safe was started.

The accelerator was divided into about 50 zones, corresponding roughly to the electrical sectors, and for each zone a detailed procedure was established for making it safe. Every piece of equipment was identified and the engineers responsible for them defined the potential hazards and the steps necessary to make them safe. This was all recorded in a series of documents establishing a hierarchy of safety levels which had to be signed off by the experts responsible for the equipment and systems. Once all of the signatures at the equipment level had been completed, there was an inspection by the dismantling project team together with the safety coordinators to verify that all was in order and finally each area was signed off as safe for dismantling activities to commence.

Within each sector the first things to be removed were the ‘nuclear’ elements which were removed by qualified personnel – it was possible to remove all of the radioactive components un-bolting them. The area was then subjected to a radiological survey to confirm the absence of all nuclear materials and it was then declared a conventional zone. Subsequently the normal dismantling teams followed, one behind the other in the sequence described above. The number of radiation workers was therefore quite limited and they were the same people who worked on the equipment during the life of the accelerator. Once the nuclear materials had been removed, the remaining equipment was in conventional areas (zone à déchets conventionnels) and any category of worker could be employed.

2.7 Radiological Protection and Traceability

These activities are dealt with in detail in the other paper concerning LEP Dismantling which is presented at this conference [1] and only a brief overview is given here. The activities of the Radiological Protection (RP) Group were extensive, starting from the initial calculations and studies related to the zoning mentioned above and on through the operational dosimetry and measurements of the dismantled equipment to the treatment of anomalies and finally the confirmation of radiological declassification of the zone.

During the preparatory phases, the RP Group carried out experiments to calibrate the activation processes and made analyses to verify the predictions of the simulations. During the execution phase, it was necessary to supplement the RP Group with a large number of qualified technicians in order to carry out the checks in the tunnel, at the loading area and at the gate monitor/weighbridge. The maximum number of technicians on this contract during one month was 15 and the total contract covered around 11 man-years. Throughout this time the RP Group also managed the personal dosimetry for all of the radiation workers concerned with dismantling.

Every load was measured for radiation and traced before it left the bottom of the access pits. Any anomalies discovered at this stage were isolated and investigated before they were allowed to leave the tunnel. The radiation measurement was recorded on-line together with the trace for all materials from the tunnel. This was achieved through a sophisticated radio link from the barcode reader to a base station connected to the corporate database.

On arrival in the SD building on top of the shaft, loads were traced and sent on to their next destination. CERN purchases all of its equipment tax free through Switzerland and special paperwork is necessary for transport of these materials on public roads in France and also rather complex customs procedures are required for the sale or destruction of such materials in France. Simplified automated procedures were negotiated with the French and Swiss authorities for the dismantling. These automated procedures were integrated in the traceability and sales systems.

The possible destinations for the materials were the various storage areas, the radioactive waste area or the loading zone on the Prevessin site and in all cases, a record of the arrival of the loads was registered in the traceability system. In the case of the dipole magnets, the excitation bars and vacuum chambers were removed in a small workshop area at the loading area and the chambers and bars placed in skips for re-cycling and the concrete/steel cores were stacked in the adjacent storage area pending use in construction projects at CERN. The first 950 dipole cores were used to construct the floor of the new radioactive storage building. A further 800 are destined for use in the LHC to build bridges and shield walls and most of the remainder will be used to build a shield wall for the CTF3 facility at CERN.

The contract for the recycling of materials from the machine was won by Excoffier Frères from Groisy, Haute Savoie. It was arranged with this contractor to have a regular supply of skips which were filled on the Prevessin site and collected at a schedule determined on a week to week basis. Materials from the machine were taken from the LEP sites by the CERN transport service and on arrival at the Prevessin site they were driven through the radiation detector before being taken into the loading area. This process was useful for identifying concentrations of very low level radioactivity which were not found during the measurement of individual elements. When the materials were removed by the contractor, the traceability identifiers were sent electronically from the transit zone to the weigh bridge office where they were entered into the sales documents. Once the vehicle and its load had been successfully checked for radiation and weighed, an automated process produced customs documents and sales documents and sent the information electronically to the Finance Division for invoicing.

The location of the weigh bridge and radiation detector (‘portique’) was determined by the proximity to the loading area which itself could not fit into many locations on CERN property because of its size. From a radiation measurement point of view, the detector was not ideally situated because it was sensitive enough to be affected by low levels of stray radiation coming from the Super Proton Synchrotron (SPS) hundreds of metres away and from the nearby SPS target area. The effects on the instrument were a general increase in background levels corresponding to beam in the SPS, peaks from beam losses and background from induced activity in the target area which decreased once beam was stopped. Fortunately most of the dismantling work coincided with a very long shutdown in the SPS but there were some months of overlap.

2.8 Human Resources

In the early stages of the project around 30 people were concerned with the "Working Group for the Transformation of LEP' which met around once per month during 1998. Towards the end of that year and during 1999 people spent more time making tests and studying the problems. From early in 1999 work was started on the preparation of the safety documents and the Project Committee was formed. Figure 5 shows the evolution of manpower throughout the project, separated into project management and organisational staff and the staff concerned with the execution of the work.

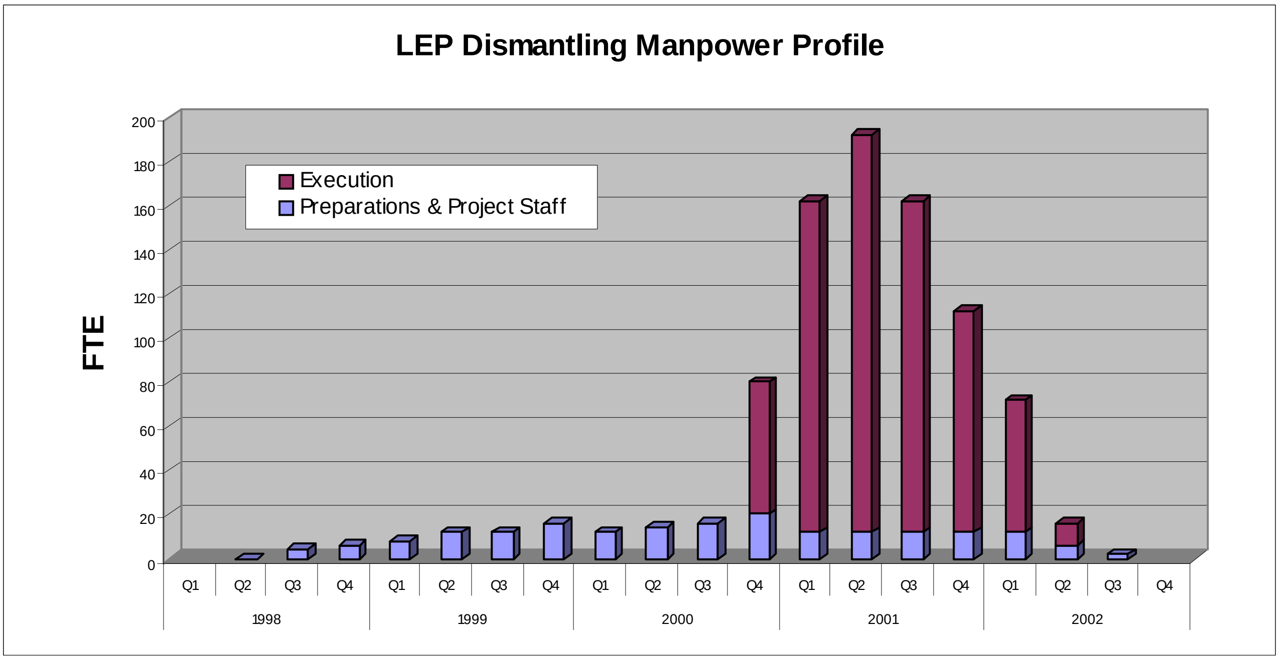

Figure 5 Quarterly distribution of manpower throughout the project

At the end of 1999 there was a step increase caused by the intense activities during November in order to prepare safety documents concerning the experiments. Following this a large number of people were involved in the placing of barcode stickers on equipment in the tunnel during the LEP shutdown and also in the procurement activities.

Teams for the execution were scheduled to arrive in the fourth quarter of 2000 but following exciting physics developments, LEP was still running and the arrival of as many people as possible was delayed until after Christmas when removal of equipment really started. It had been hoped that work would be completed by Christmas 2001 but problems with transport and handling equipment and additional safety procedures led to the continuation in 2002. Most of the teams recruited for the execution finished at the end of February 2002 but some equipment remained to be removed and there were a number of other activities associated with the final cleanup which also continued.

The total manpower used in the project was around 240 man-years, of which around 15% came from CERN staff.

2.9 Documentation and Quality Assurance

LEP became an INB in 1985 following the signature of a convention between CERN and the French Government. This convention was rescinded in November 2000 and replaced by a similar convention signed in July 2000 which covered the Dismantling of LEP, the LHC , the SPS and the CNGS (CERN Neutrino to Gran Sasso Project).

The first discussions with the French authorities concerning LEP Dismantling took place in 1998 and a first version of the safety document was presented in September 1999. A second version, which included the requested revisions was sent in June 2000. The latter covered both the LEP machine itself and in the annexes, the four experiments. Final addenda were sent in September 2000. The document included:

- A safety document concerning the machine itself, including a description of the facility, the dismantling procedures, an inventory of risks and their evaluation, a description of the safety organisation, quality assurance and the impact of the whole process.
- General operating procedures for dismantling concerning the organisational aspects, the quality assurance procedures during dismantling, presentation of the operating environment, the waste and effluents, the operational manuals and the procedures to follow in case of an accident.
- A waste study which includes the radiological zoning, waste management procedures, waste disposal channels and the impact of the whole procedure in terms of waste production and radiation doses.
- An annex concerning the experiments which contained:
  - A generic radiological zoning for the four experiments
  - A waste study and risk analysis per experiment

A very large number of experts at CERN (engineers and physicists) were required to produce and edit the 300 page document. It is estimated that a total of 4 man-years was required to prepare the safety documentation.

3 Experience and Lessons

3.1 Cost

In 1996 the total cost of the project was estimated and a figure of ~12 MCHF was entered in CERN's medium term financial plan for the purchase of materials and placement of additional contracts. At this time, neither the constraints relating to LHC civil engineering nor the INB regulations were taken into account.

During the preparatory phases of the project (1999-2000) there was barely enough manpower available for the preparation of the documentation and for solving the technical problems. As a result of this it was not possible to evaluate the cost of the project until the last quarter of 1999 and in early 2000 the total cost was estimated at 19 MCHF. During the year 2000, it was discovered that certain facilities required for the project (e.g. storage areas for radioactive waste) would not be available because the departments responsible for them did not have the necessary budgets to prepare them. It was decided at this time to pay for these facilities with project money.

During this period the LHC civil engineering schedule was modified and the project management was asked to arrange for a number of additional facilities to be dismantled (e.g. the monorail where it would interfere with contractor's equipment). At the end of 2000, the physics programme on LEP was extended after the preparatory phase had been completed. The net result of all of these changes was a final total cost of around 23 MCHF (16 M€) for materials and additional contracts, making a grand total of about 30 MCHF (20 M€) when one includes the cost of CERN personnel.

The income from sales of scrap materials was lower than the estimate for two main reasons: firstly, it had been very difficult to estimate the quantities involved because many of the records from installation of LEP had been lost. Secondly a significant quantity of the materials removed from the tunnel were classified as radioactive after the contract had been established and therefore they could not be sold. The final result of these effects was an income at the lower limit on the contract, 20% below the nominal amount.

3.2 Waste and Recycling

The materials and equipment removed from the LEP machine were split roughly equally in weight between sales for recycling and re-use at CERN. Only a small fraction of the waste was radioactive (<2%) and close to 3% of the total weight was classified as radioactive waste. Table 1 lists the equipment which was classified 'TFA' (très faiblement actif) and it can be seen that there is a significant quantity which would be classed as conventional outside of France. These figures do not include the weight of around 500 items in the waste category and 140 elements in the RF system because they have not been weighed. These unweighed parts are identified by barcodes but are generally grouped in containers in varying quantities and at the time of writing it has not been necessary to weigh them. It has been estimated that the total weight of these items is less than 100 t.

Table 1 Composition of equipment and materials classified TFA

Storage Area	**Comments**	**Number of Pieces**	**Total Weight**	**Weight >0.1 uSv/h**
Waste ISR-6		2422	**757**	**475**
for re-use ISR-7	Acceleration system	1373	**578**	**531**
UX45	Dipole cores - LHC bridge	102	**519**	**229**
BB5	magnets for LHC	48	**318**	**281**
156 (PS)	Quadrupoles - future machine	12	**52**	**30**
867/RF-09	Injection dipoles - future machine	6	**30**	**15**
940	Lead shielding	24	**8**	**2**
955	Beam instrumentation	27	**9**	**2**
SPS	Equipment re-utilised in SPS	8	**9**	**2**
867	Kicker tanks for LHC	47	**11**	**7**
927	Vacuum equipment	177	**8**	**4**
SM18	RF cavity - for Korea	1	**6**	**6**
others	Areas with <1 tonne	108	**5**	**4**
FERMILAB (USA)	Magnets for FNAL	51	**103**	**62**
BNL (USA)	Injection equipment	52	**7**	**5**
		Total TFA in tonnes	**2420**	**1655**

Table 2 gives the details of the quantities of equipment that were sold for re-cycling. It can be seen that a total of nearly 9.5 ktonnes was removed from CERN and processed by the recycling agencies.

Table 2 Materials sold for re-cycling

Elements	**Weight (t)**
Pipework, seals, nuts and bolts	1118
RF cavities	17
Bus-bars	792
Excitation bars	905
Cables (Cu)	778
Cables (Al)	1146
Magnets girders	2654
Pipework supports, ventilation tubes, nuts and bolts, cable trays and miscellaneous.	1013
Dipole jacks	88
Electrical junction boxes	39
Electronics racks	53
Vacuum chambers	783
Miscellaneous	93
TOTAL	**9479**

Table 3 summarises the quantities of equipment which were donated to institutes around the world. By mid 2002, 31 institutes had requested and been awarded equipment from LEP. Institutes wishing to receive equipment were required to make formal application to the Director General of CERN stating what they would do with the equipment and proposal for gifts of equipment were presented to the Finance Committee for approval. Following approval of the proposals the institutes were required to send a contractual letter in which they stated that they knew that the equipment was coming from an INB and that there was no legal impediment to their receiving it.

Table 3 Disposal of Conventional (non-radioactive) Materials

Non-nuclear materials	**Weight (tonnes)**
Reused at CERN	6183
Given to institutes	274
Destroyed (batteries, halogens etc.)	30
Dipole cores stored	10959
Total	17446

From the preceding tables it can be seen that a total of around 29.4 ktonnes was removed from the LEP machine during the Dismantling Project.

3.3 Technical Problems

Before the dismantling started, preventive maintenance was scheduled for all of the transport equipment like the mono-rail, overhead cranes, personnel carriers (tunnel tractors) and trailers, giving special attention to the equipment which would be heavily used.

In spite of these precautions the project was struck by numerous costly failures in the transport equipment. One of the main overhead cranes was out of service for nearly 14 weeks and during the first few months of execution, the monorail frequently broke down. These problems stemmed from poor maintenance, the age of the equipment, lack of spare parts in stock and difficulties in obtaining spares for the ageing equipment.

The problems encountered with the tunnel tractors were also to some extent due to the reasons listed above but also to mis-use and vandalism by the contractors working in the tunnel.

The overall effect on the safety, smooth running of the project, the planning, and the cost was very bad – for example, the project was delayed by more than 12 weeks because of problems with the overhead cranes.

The use of hydraulic nibblers for cutting the equipment was certainly a good one however, in the early months many of the cutting blades were broken and the rate of wear was higher than expected. The supplier was able to identify the cause of the problem and by reducing the hydraulic pressure and employing a special surface treatment on the blades the performance was significantly improved. The purchase of a spare nibbler enabled work to continue whilst another was being repaired.

Apart from the problems related to the dismantling and transport equipment itself, the main cause of problems was the lack of competence and/or training of the contractors personnel. Furthermore, there was a lack of supervision on site by the contractors during the early part of the project which lead to safety hazards because the workers were not properly trained and initially there were insufficient numbers. These problems led to delays in the project because it was not possible to meet the required rate of progress and they also led to damage to equipment and the infrastructure.

It should also be noted that there were insufficient CERN personnel available for the supervision and follow up of the work: an additional 7-10 man years was probably needed.

3.4 Incidents and Accidents

During the execution of the project there were a large number of small incidents and accidents. Whilst the seriousness of these was relatively low, the frequency was rather high. In June 2001 it was decided to take some steps to try and improve the situation and all of the people who were working on the project (both underground and on the surface) were required to attend a special safety briefing. Following this there was a significant improvement.

All accidents and incidents were reported to the safety coordinators who made investigations and reported back to the project management. In 15 of the 43 cases a formal report was made and the recommendations were followed up through the normal supervisory channels.

Accidents which did not require a report often concerned minor injuries like a twisted ankle or minor cuts and bruises. The accidents which required a more formal enquiry and report concerned such things as loads which were dropped from a fork lift truck, the OPAL coil rolling off its trailer and injuries received during handling operations.

About 85% of the recorded incidents concerned the company responsible for transport and handling. This company carried out about 50% of the work (in terms of man-years) during the execution phase and it included cutting of the magnet coils and busbars as well as all of the handling and transport operations.

There were two incidents of greater magnitude during execution of dismantling – a fork lift truck rolled over and a dipole magnet fell from the crane in the shaft at point 4 – both of them resulting in a full enquiry by an accident board appointed by the Director General. Neither of these incidents had any serious consequence for the health of anyone but could have easily been far worse. The first incident occurred in April 2001 during the removal of magnets from the transfer lines which are on a sloping floor. There was a brake failure on the special truck which was assigned to this task. The driver was able to jump from the vehicle and direct it towards the wall in order to stop it from rolling further down the tunnel. When the forks came into contact with the curved vertical cross-section of the tunnel, they were lifted sufficiently to roll the truck over. Following the enquiry the truck was no longer qualified to work on sloping floors and as a consequence some magnets could not be removed from the transfer lines.

In September 2001 a dipole magnet (load of 5t) which was being lifted from the tunnel at point 4 slipped from its slings and fell from about 100m into the tunnel. Fortunately no-one was struck by the flying debris which resulted from this accident. In this case the main changes resulting from the enquiry were the implementation of new procedures for slinging and lifting dipole magnets and a large exclusion zone for personnel at the base of the shaft during lifting operations.

The procedure for placement of contracts at CERN takes about 12 months and their specification was late because this depended on the way in which dismantling would be done. Before the contract specification could be drawn up, technical and regulatory decisions and approval are required. Given a lead time of more than one year between the announcement of market surveys (when the technical decisions have been made) and the start of a contract, there was very little time to properly prepare the technical specifications. However, the contracts were placed in time and in general they ran quite well.

The contract for the sale of scrap materials from the machine was probably the most difficult of the contracts for a number of reasons. The call for tender was open to companies in all member states and was restricted in France to companies with ICPE 2799 status. The fact that the materials had to be removed from CERN, meant that transport costs were a significant factor for the contractors and therefore only companies within a relatively close proximity to CERN were able to be competitive. In addition, the fact that there is only one French company in the vicinity that was qualified did not place CERN in a competitive position. As it turned out, the French company won the contract on the most favourable price. During the contract there were some commercial disagreements between CERN and the contractor and it was several months before a compromise solution was reached.

It was possible for the transport contract managers to slow down the start of their contract when the LEP run was extended but it turned out to be quite difficult to increase the manpower levels as rapidly as was requested by the project management. During the first six months of dismantling it was necessary to apply considerable pressure on the company in order to meet the safety and performance requirements of the project.

3.5 Personnel Problems

As was mentioned above, the inexperience and the lack of supervision of contractor’s personnel was a major problem. Other problems were the result of people not following the operational/safety procedures and it was necessary to constantly remind them of how they should be working.

These constant reminders of the procedures and the application of sanctions against repetitive offenders were absolutely necessary to maintain safety standards and to protect CERN’s equipment. Personnel who repeatedly did not wear their safety helmets, safety shoes or carry their oxygen masks and those who broke the rule of one person per tractor were sanctioned. It was clearly stated by the project management that further offences would lead to the person concerned having his right of access to the work site removed.

There were some initial problems with the contract for the cutting and removal of the pipe work. The company which won the contract brought the personnel from the Czech Republic and it was necessary for the company to obtain visas for all of them. The regulations and requirements were made quite clear to the company, but it seemed that they were not used to normal working practices in Western Europe. It was the first time that this contractor had worked at CERN and it took several months after the signature of the contract before any personnel were available and then it was some time before the work force was at the required strength. Once the team was established however, they were highly motivated and efficient.

3.6 General Organisation

The principle of having a strategic and an operational level of management of the project worked well. It is clear however, that the technical activities and the strategic planning at the start of the project should have been fully operational 6-12 months earlier. Given this earlier start, the work could have been better prepared and then executed in a more efficient way. For example, feedback from the French authorities would have been earlier and changes to our procedures could have been made during the planning stage rather than having to make costly changes after preparations had begun.

3.7 Traceability

The idea to install 22000 barcode stickers on all elements in the 1999-2000 shutdown was perhaps not all that should have been done. Having an inventory for many types of equipment which would be removed was very useful but during the actual evacuation of equipment the loads which were transported did not correspond to one barcode. In the case of vacuum valves, for example, it was decided to place them in containers for evacuation, but each one had already been identified and labelled. There were many such cases and the feeling was that it would have been better to label some items once they had been identified as one load or container. At the end of dismantling around 67000 items had been defined and traced by the system.

A related problem was the establishment of the inventory of what had been installed in the tunnel and finding out the chemical composition of the various types of equipment. This chemical composition was important for two activities – radioactive waste management and the sale of scrap materials. It was necessary to make estimations of the quantities of the various metallic elements for the scrap sales and this proved to be very difficult because of the lack of records.

3.8 Radiological Protection

One of the main problems which occurred early during dismantling was the so-called mass effect. The equipment leaving the tunnel was checked piece by piece and subsequently placed in large containers for evacuation. Since the gate monitor measures ionising radiation and does not measure specific activity it was possible that an assembled load could trigger the alarm because it contained a large number of items with very, very low specific activity (contact dose rates typically <50 nSv/h, implying <0.1 Bq/g). When this happened it was necessary for the vehicle to return to the loading area and the load was discharged in a special area where it was checked again, piece by piece. For a load of more than 10 t this was a lot of work. Once the problem had been understood, procedures were modified so that shipments of this nature could be identified before they were loaded on the contractor's vehicles.

The removal of radioactive equipment from the tunnel was of course planned on the principle of ALARA and the resultant doses were satisfyingly low. The integrated total accumulated dose was <7mSv for the 236 people concerned, the maximum integrated personal dose was 549 μSv and the average was 29 μSv: all below the target values.

3.9 Waste Management

One problem which resulted from the poor knowledge of exactly what had been installed in the tunnel was for the radioactive waste management. When parts of the machine were removed and delivered for storage as radioactive waste, the chemical composition was not always known because records had not been kept from the construction period. This information had to be derived retrospectively.

Because the storage areas were not completely ready at the start of the project and because the total volumes which had to be stored were significantly larger than expected the storage was not optimised from a waste management point of view. The priority was given to optimising the occupation of the available space.

3.10 Zoning

The imprecise knowledge of the history of the accelerator was a problem for the establishment of the radiological zoning. During 11 years of operation LEP was operated at many different energies and with many different magnetic configurations. The complexity of these configurations made the simulation of beam losses impossible to do in an exact way. In the case of the superconducting RF cavities, the activation was related to the surface properties of the superconductor which varied dramatically from one module to another. During conditioning of the cavities and during operation, there was field emission of electrons from impurities on the surface and these could be accelerated to sufficiently high energies by the cavity fields that intense bremsstrahlung were generated which in turn induced photonuclear reactions which produced neutrons. Each module had its own particular history and behaviour and it was therefore impossible to predict which components could have been activated in these areas and therefore the whole region within an 80 cm radius around the beam throughout the RF sections was classified as nuclear. This region excluded the tunnel walls, cable trays and cables and pipe work but it included all of the accelerator components.

The final zoning proved to be quite accurate because the number of anomalies was fairly small, representing <2% of the total weight. On the other hand, an equivalent mass of the material classified TFA by the zoning was not radioactive. Whilst these percentages are small they represent several hundred m^3 in each category.

3.11 Recycling Procedures

In general the equipment was removed from the Prevessin site following the required schedule. The only problems encountered were the commercial aspects mentioned above and the difficulties early in 2001 with the ‘mass effect’. It was a risk however, to have a single company dealing with the purchase of the scrap because if there had been any problems with the removal of materials from the loading area, the dismantling activities in the tunnel would have had to stop since there was nowhere else to store the materials.

Removal of equipment from the tunnel was however, much more problematic because of the difficulties with the transport and handling equipment (monorail and cranes). During the period when the cranes were out of service, equipment was buffered in the klystron galleries. This allowed the dismantling teams to continue their progress in the tunnel and thanks to the flexibility of the transport team it was possible to get back on schedule by working extra shifts and overtime.

3.12 Safety

CERN has operated for many years in an environment which is like a university research laboratory and the transformation to an industrial work site brought about by LEP dismantling required fundamental cultural changes. It was estimated that the initial period of making the areas safe would present the greatest risk and therefore this period was not rushed and the procedures were strictly applied – this worked very well and there were no accidents during this period. Because of the delay to the start of dismantling due to the extended period of physics running of LEP, there were problems to get the dismantling teams up to strength before the Christmas period. There was a positive aspect to this however, the teams responsible for making the areas safe were composed of CERN staff and therefore already in situ and they were able to work in a more relaxed time frame.

An interesting phenomenon was observed during the safety training. The access rights of all personnel were revoked before the start of the project and people needing to work in LEP were required to attend a special safety training before their access rights were re-established. It had been estimated that around a total of 400 people would work in the tunnel during the dismantling project and therefore a few training sessions were planned. By the Spring of 2001, more than 2500 people had attended the safety training ! We can only attribute this to a psychological effect whereby people felt that one of their ‘privileges’ had been removed – certainly no more than 400 people really needed the access permission and no more than this actually went into the tunnel.

The safety coordinators worked very well with both the contractors and the dismantling team so that safety matters were handled in a very positive framework. There were some difficulties initially to get the contractors’ safety plans established and agreed, but these were all completed before the work was scheduled to start and proved to have a very positive impact on safety in general.

3.13 Security

Maintaining security across many different sites which are relatively open was quite difficult. There are nine remote sites for LEP covering an average of five hectares each and having a total of around 90 major buildings and numerous barracks and storage areas. During normal operation all materials would be either installed or within locked buildings but this was not the case during dismantling. The investment of more than 1.5 MCHF (>1 M€) for additional security personnel was therefore fully justified and as mentioned earlier, the personnel were even able to contribute directly to the dismantling activities.

3.14 Interactions Between Work in the Accelerator Tunnel and the Experiments

The interaction between the machine and the experiments was kept to a strict minimum because of the different procedures which were applied. In order to do this, physical barriers were established to separate the flows of equipment and different routes were used by the personnel. At the planning stage, there was good communication amongst the five projects and in many cases procedures were shared. The safety training which was required for all personnel wishing to go to the underground areas during dismantling was prepared in a collaboration amongst the coordinators for each experiment and the machine dismantling team. This worked well and it was useful for everyone working underground to follow more-or-less the same rules and regulations.

4. Conclusions

The LEP Dismantling Project was not the first time an accelerator was dismantled at CERN, but it was the first one in the INB context and it was much larger than anything that had ever been done before. Given the scale and the constraint of being an INB this was a major challenge for CERN which has always operated in a less formalistic (laboratory) way. CERN’s engineers and physicists are used to a research environment of which they are the masters and the transition to an industrial environment was not an easy one.

The modus operandi for dismantling an INB also required a cultural change for us because we would normally expect to have a set of rules and regulations to which we should conform. However, the process of having some basic guidelines and then effectively defining the regulations ourselves and then to have them approved by DSIN was not easy and perhaps not the most cost effective solution. It is easy to define a set of procedures which would be accepted by the authority but which would cost far more than something less sophisticated or extensive but still acceptable. Given the short timescale for the preparation of the documentation and having no similar projects from which we could learn, we probably did more than was necessary in certain areas. One example of this concerned the radiation measurements which were made in the tunnel: the background levels in the tunnel are about half of the level of those at the surface, so in order to identify anomalies from the zoning, the threshold for alarms on the measurements was set well below the ambient level at the surface. The result of this was a number of loads were tagged initially as anomalies whereas the specific activity was extremely low (<0.1Bq/g) and it would not have been possible to detect any activity on the surface. Whilst this is a very safe procedure and represented the best measurement that could be achieved, it resulted in some additional work later on and a modified procedure could perhaps have achieved satisfactory safety levels but avoided the additional work.

In our accelerator environment establishing the radiological zoning is a complex and expensive task and it is not clear that the result will be particularly useful. The size of CERN’s accelerators (SPS 7 km circumference, LHC 27 km circumference) means that even small errors in the zoning can lead to the requirement of storing large volumes of equipment which are not activated.

An obvious area of concern for us is the absence of a threshold value for the release of active materials – it seems an aberration in the European context that this should be the case. Of equal impact is the fact that we cannot easily (if at all) de-classify materials classified TFA by the zoning but which have clearly not been activated. Given the absence of any channel for disposal of radioactive waste, having to store non-active TFA within expensive radioactive storage areas is something we would like to see changed.

Managing large numbers of contractors who are all working in close proximity was not an easy task and CERN will benefit from the lessons learnt during dismantling for the installation of LHC. Unfortunately much of what we learnt about dismantling an INB will probably be of little use by the time we have to dismantle another accelerator at CERN but we hope that others may profit from our experience.

The success of the LEP Dismantling Project was due to the dedication, enthusiasm and hard work by all of those who contributed: they are far too numerous to mention by name here, but I would like to express my personal thanks to them at this time.

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