APPENDIX E

RADIOLOGICAL AND ENVIRONMENTAL IMPACTS OF THE CHORNOBYL ACCIDENT

E1 INTRODUCTION

The following text is largely based on the results of two international conferences held in 1996 to discuss the impacts of the Chornobyl accident [E1, E2].

E2 BACKGROUND

The explosion at Chornobyl Unit 4 on 26 April 1986 at 01.23 destroyed the reactor core and the building in which it was housed. Hot material expelled from the reactor started fires which lifted further radioactivity high into the atmosphere as temperatures rose. Despite heroic efforts by the Soviet response teams involving up to 800,000 persons, releases were not curtailed until more than ten days after the initial explosion. Relatively minor releases then continued until autumn 1986 when the remains of the reactor were entombed in a shielded 'sarcophagus'.

Radioactivity released by the explosion and the ensuing fires was dispersed locally, regionally and, by injection into the stratosphere, globally. In August 1986 the true extent of the disaster started to become clear when Soviet scientists and engineers presented an account of the accident to IAEA [E3]. It was a further 2 to 3 years before reliable information on the local environmental consequences became available as more scientists from the west visited the affected regions, but it was not until the collapse of the Iron Curtain in late 1989 that a clear and comprehensive account could start to be formulated. Before 1991 it was not possible to address the likely health consequences and even today there are uncertainties on this matter except for the specific case of thyroid cancer.

E3 THE SOURCE TERM

Initial estimates presented to the IAEA indicated that ~1 MCi ($3.7x10^{16}$ Bq) of ^{137}Cs was released (13% of the estimated inventory) along with 7 MCi ($2.6x10^{17}$ Bq) ^{131}I, 0.2 MCi ($8x10^{15}$ Bq) ^{90}Sr and 2,400 Ci ($9x10^{13}$ Bq) of alpha-emitting plutonium isotopes (Pu-α). As time went by, the ^{137}Cs releases were re-evaluated to suggest first that 20% and then that 33∀10% of the initial inventory had been released. It is now known that some 15 to 23 kg of plutonium were released, the majority being confined to within 80 km of the damaged reactor. A significant component of the Chornobyl release was in the form of 'hot' particles composed either of fuel fragments or formed as condensation particles at different stages of the fire.

E4 ENVIRONMENTAL CONSEQUENCES - EUROPE

Radioactivity first moved north towards Scandinavia and only later south and west through Europe, before reaching the UK on the afternoon of 2 May 1986. Some of the heaviest depositions of radiocaesium (^{134,137}Cs) occurred in conjunction with rainfall and were recorded in Scandinavia, Germany, Austria and Switzerland amounting to several hundred kBq/m^2 locally and several tens of kBq/m^2 regionally. In the UK, maximum deposits of ^{137}Cs (in excess of 20 kBq/m^2) occurred in the North West whereas ^{131}I, which was less influenced by rainfall, was more evenly deposited with deposition decreasing with increasing distance from the source. Aerial monitoring in Scandinavia and later in the UK emphasised the highly variable nature of the deposit. In general, deposits of ^{90}Sr and the actinides in Europe were low relative to the initial source term.

Since the deposit occurred in parts of Europe at a time at which animals were only just beginning to graze fresh pasture, the pattern of concentration in milk with time was highly variable. In several northern countries peak concentrations in milk did not occur until June or July 1986.

During summer and autumn 1986 ^{137}Cs concentrations in vegetation generally declined very rapidly. Exceptions included vegetation developed on organic and sandy soils and, in particular, semi-natural grasslands where variation in uptake between individual species combined with the lack of significant binding capacity for radiocaesium in soil, caused concentrations to decline only very slowly. Concern in winter 1986 over the possible trends in the following spring lead to studies in several European countries on the soil-to-plant transfer of Chornobyl radionuclides. These studies indicated that problems experienced in specific environments in 1986 would continue for several years. The explanation was thought to lie in the low potassium status of the problem soils but this was subsequently proved to be too simple an explanation, at least for semi-natural pastures on organic soils, where cycling within the vegetation and the surface layer was equally important in preventing removal of radiocaesium by migration or overland flow.

Concentrations of radiocaesium in animal products reflected, to a large extent, herbage concentrations with a delay time that corresponded to turnover times in different tissues, particularly muscles. However, for animals typical of semi-natural environments (e.g. sheep, reindeer, goats and game) there were clear early indications of variability that could not be attributed either to the general level of deposition or to concentration in vegetation. For reindeer, the explanation was the known concentration of radiocaesium by lichens, the consequences of which could be controlled by timing the slaughtering of animals relative to summer and winter grazing periods. In Scandinavia, concentrations in some game species increased at times of the year and in years in which fungal fruiting bodies proliferated. Agricultural practice was also a dominant factor. Transfer factors to animal products measured in early 1986 were often reported to be lower than those determined previously for ionic caesium indicating that, in some cases, the material deposited from Chornobyl was partially chemically unavailable.

Freshwater ecosystems also showed extensive contamination both in the short term as a consequence of direct input and in the longer term as a consequence of runoff from contaminated watersheds. Nevertheless, in many systems, concentrations of radiocaesium in water declined rapidly as a result of binding to the clay components of suspended and deposited sediments. Plants and animals which received their inputs primarily from the solution phase also showed a similar rapid decline. In contrast, those which received their inputs from sediment-borne radiocaesium increased in concentration with time to reach peaks at periods up to three years after the fallout occurred. As for terrestrial ecosystems, those freshwater systems with a low potassium status or low clay content continued to produce contaminated products for several years unless countermeasures were applied.

E5 ENVIRONMENTAL CONSEQUENCES - FORMER SOVIET UNION

Immediately after the accident emphasis was placed on localising the contaminated sites and fixing dusts to prevent secondary contamination. Forests in the immediate vicinity of the NPP were felled to prevent fires and were buried in shallow trenches. Approximately 800 temporary waste disposal sites were created containing $4x10^6$ m^3 of waste. Since the NPP is surrounded by land that used to be periodically waterlogged it was necessary to take immediate action to protect water supplies to cities such as Kyiv. Over 130 dams and dykes were constructed, some containing special filter beds. Upper layers of soil were limed and a grass cover established to reduce wind blow, followed by the planting of 40,000 ha of forest. In this first stage of action, measures were often required at ^{137}Cs contamination levels >15 Ci/km^2 (1 Ci/km^2 = 37 kBq/m^2). A major effort was required to map the extent of radioactive contamination not only in the immediate vicinity of Chornobyl but also at increasing distance as more hot spots were discovered; this work culminated in production of an atlas of radiocaesium deposition throughout Europe.

Immediately after the accident, an 'exclusion' zone was instigated around the NPP with one boundary (the '10 km' zone) following the ^{137}Cs >40 Ci/km^2 isoline, and another (the '30 km' zone) following either the >15 Ci ^{137}Cs/km^2, or the >2 Ci ^{90}Sr/km^2, or the >0.1 Ci Pu-α/km^2 isolines. In early 1990, official estimates put the total area contaminated with ^{137}Cs at >5 Ci/km^2 at 25,000 km^2. This estimate was then increased to about 28,000 km^2 and then to 30,000 km^2. The area contaminated at >1 Ci/km^2 is currently estimated as 145,000 km^2.

E6 EFFECTS ON THE LOCAL POPULATION

Information on the number of people directly affected by the disaster changed as the results of mapping became available. By 1989 it was clear that approximately 3.8 million people were inhabiting regions contaminated at >1 Ci/km^2 ^{137}Cs. Shortly after the accident 135,000 people were evacuated from the exclusion zone. Subsequently a further 210,000 persons were relocated from areas outside the exclusion zone.

From 1987 to 1989 emphasis was placed on the control of food product contamination using control limits based on a lifetime dose commitment of 350 mSv. Further work continued on the removal of contaminated soils and sediments and on the modification of agricultural practice and food production technology. These measures had varying degrees of success and it soon became clear that agriculture, even using State-run systems, might need to be limited in some areas containing >1-5 Ci/km^2 ^{137}Cs.

From 1990 onwards, the introduction of more stringent limits on dose placed even greater constraints on agricultural production in the contaminated regions and several of the measures introduced in earlier years proved to be unsuccessful. Particular problems were associated with private milk production, peaty or marshy soils, and forestry. The situation became even more complicated in some areas by solubilisation of radionuclides in particles initially of low solubility. In addition, major works continued on the flood plain of the Dnieper. Future efforts are required to deal with the temporary waste disposal sites which are known to contain between 300 and 350 kCi of radioactive waste.

Of the 237 individuals suspected of suffering acute radiation sickness diagnosis was confirmed in 134. Twenty eight of these have died as a direct result and a further 17 have died but not necessarily as a direct result of radiation exposure.

Two hundred thousand of the 800,000 persons who participated in the clean-up received external doses >100 mSv. An increased incidence of cancers (including leukaemias) is forecast for this group and for the initial evacuees but was not detectable against background by 1996.

The main direct effect of the disaster is the increase in thyroid carcinomas in the cohort of children that had been conceived up to six months before the accident. The reported number of thyroid cancers in this group up to the end of 1995 was 800, with 400 in Belarus alone. These cancers respond favourably to treatment if appropriately applied and replacement hormone therapy ensures reasonable quality of life.

E7 REFERENCES

E1 EC/IAEA/WHO. One decade after Chernobyl: Summing up the consequences of the accident. Austria Centre, Vienna, Austria. 8-12 April 1996.

E2 EUR 16544 EN. The Radiological consequences of the Chernobyl accident, Proceedings of the first international conference Minsk, Belarus, 18-22 March 1996.

E3 IAEA. Summary report on the post-accident review meeting on the Chernobyl accident. Safety Series No. 75-INSAG-1. September 1986.