4. Summary of Data Reported and Evaluation

4.1 Exposure data

Radon and its decay products are ubiquitous in soil, water and air. Radon in the ground, ground-water or building materials enters working and living spaces and disintegrates into its decay products. In comparison with levels in outdoor air, the concentrations of radon and its short-lived decay products to which humans are exposed in confined air spaces, particularly in underground work areas such as mines and in buildings, are elevated. In those houses where the concentrations of radon are high, the primary source is usually the ground under the structure. Although high concentrations of radon in ground-water may contribute to human exposure through ingestion, the radiation dose to the body due to inhalation of radon released from the water is usually more important.

Concentrations of radon decay products measured in the air of underground mines throughout the world vary by several orders of magnitude. In countries for which data were available, concentrations of radon decay products in underground mines are now typically less than 1000 Bq/m^3 EEC_{Rn}. The concentration of radon and its decay products in houses also varies widely — by as much as four orders of magnitude. The average radon concentrations in houses are generally much lower than the average radon concentrations in underground ore mines; however, in many countries where surveys have been performed, the concentrations of radon and its decay products in a small percentage of houses are comparable to the concentrations observed in many underground mines.

4.2 Experimental carcinogenicity data

Radon and its decay products were tested for carcinogenicity in inhalation experiments in male rats and hamsters and in dogs of both sexes. In rats and dogs, a significant increase in

the incidence of respiratory tract tumours was observed in comparison with unexposed animals. A dose-response relationship was noted in those experiments in rats in which it was tested. In most instances, tumours at sites other than the lung were not reported, but, in one study, mention was made of tumours of the upper lip and urinary tract in rats.

Three treatments (inhalation of cigarette smoke, inhalation of cerium hydroxide particles and repeated intraperitoneal injections of benzo-5,6-flavone) increased the incidence of respiratory-tract tumours in rats exposed to radon and its decay products.

4.3 Human carcinogenicity data

Raised lung cancer rates have been reported from a number of cohort and case-control studies of underground miners exposed to radon and its decay products. These include particularly uranium miners, but also groups of iron-ore and other metal miners, and one group of fluorspar miners. Strong evidence for exposure-response relationships has been obtained from several of these studies, in spite of uncertainties that affect estimates of the exposure of the study populations to radon decay products. Several small case-control studies of lung cancer have suggested a higher risk among individuals living in houses known or presumed to have higher levels of radon and its decay products than among individuals with lower presumed exposure in houses.

The evidence on the interaction of radon and its decay products with cigarette smoking with regard to lung cancer does not lead to a simple conclusion. The data from the largest study are consistent with a multiplicative or submultiplicative model and reject an additive model. Some other studies with smaller numbers do not clearly support this finding.

In many studies of miners and in one of 'presumed' domestic exposure, small-cell cancers accounted for a greater proportion than expected of the lung cancer cases. In one population of uranium miners, this proportion has been declining with the passage of time.

4.4 Other relevant data

The effects of radon are largely attributable to the inhalation of its decay products. The pattern of their deposition in the respiratory tract is dependent on whether they are attached to particles or not. Deposition of the attached fraction is determined by the size of the particles in the associated aerosol. Following inhalation of radon and its decay products by experimental animals, the highest concentrations of short-lived decay products occur in the tracheobronchial and pulmonary region and in the kidney.

Although exposure of experimental animals to high levels of radon and its decay products can cause death, there is no evidence of any acute toxicity to humans from levels to which humans have been exposed.

In some, but not all, studies of groups of people either occupationally exposed to, or resident in areas of, high natural radiation, including elevated levels of radon and its decay products, an increased incidence of chromosomal aberrations has been observed. Radon and its decay products did not induce chromosomal aberrations *in vivo* in rabbits in one laboratory experiment but did induce chromosomal aberrations in human cells *in vitro* and sex-linked recessive lethal mutations in *Drosophila.*

4.5 Evaluation[1]

There is *sufficient evidence* for the carcinogenicity of radon and its decay products in experimental animals.

There is *sufficient evidence* for the carcinogenicity of radon and its decay products in humans.

Overall evaluation

Radon and its decay products *are carcinogenic to humans (Group 1).*