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A report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly, with annexes

VOLUME I: LEVELS

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NOTE

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Annex C

DOSES FROM OCCUPATIONAL EXPOSURE

CONTENTS

Introduction

1. In its 1962 report (72) the Committee discussed the contribution made by occupational exposure to the population dose. At that time it was concluded that the genetically-significant dose (GSD) from this source was unlikely to exceed a value of 0.5 millirem per year. The 1962 report also presented information on the numbers of workers in various countries, and on the doses being received by workers in various categories of work involving exposure to radiation.

2. The purpose of the present annex is to present new information with which the 1962 report can be updated.

I. Sources of information

3. Surprisingly little information on occupational exposure has been published in the scientific literature, although a considerable body of data is reported in sources of limited availability, such as annual reports of various organizations. Some of the information in this report has been submitted to the Committee as unpublished data. Much of the submitted data has needed to be reprocessed by the Committee in order for it to be put into the form required for the report. It is to be hoped that the presentation of such a considerable amount of unpublished data will encourage the publication of similar information through the normal scientific channels.

II. Limitations of the data

4. Most of the data that the Committee has used in this report were originally obtained for other purposes, and, in particular, in personnel monitoring programmes that either were designed to check that the exposures of radiation workers do not exceed some specified level, or were required by law. For reasons described below, the data were not always suitable for deriving estimates of dose in the form required by the Committee.

5. Accurate assessment of dose at the lower exposure levels is severely limited by the fact that in personnel monitoring it is usual to ignore doses below either a minimum detectable level, or below an "investigation level"[1] selected for monitoring purposes. Because the exposures of most radiation workers are in this low range, there are few precise data on the actual doses received by them. The difficulties of selecting a representative dose value for this lower range are described in paragraph 34.

6. Another factor tending to limit the use of monitoring data for the Committee's assessment of dose is that the proportion of workers who have been supplied with personal monitoring devices varies considerably from place to place. In some establishments the staff, including those not likely to be exposed to radiation, are provided with such a device, while in others only those workers whose exposures might exceed three tenths of the annual dose limit are so monitored (see also paragraphs 16 and 17).

7. A major problem in using the results of personnel monitoring programmes to make dose estimates is concerned with the meaning of the term "dose" itself. With external radiation, irradiated personal monitoring devices undergo some change which is usually compared with the amount of change occurring in similar devices exposed under calibration conditions. In most instances the calibration devices indicate the exposure (in its strict physical sense) in the device itself, and seldom can it be said that the so-called "dose" in the test device is a true absorbed dose. Similarly, with the monitoring device worn by a worker, the change produced by irradiation, after being compared with a standard, is usually reported as a "dose", although it is not strictly an "absorbed dose".

8. Of more significance, however, is the fact that the "dose" estimated for the monitoring device is usually assumed to represent the "dose" in tissue in the person wearing the device. At the low dose levels encountered by most radiation workers it is not usual to assess the actual absorbed dose in tissue by taking account of factors such as depth, direction, and energy of the radiation; instead, for radiation protection pur-

[1] For a description of this concept see reference 24.

poses, the rough assumption is made that the "dose" in the monitoring device is the same as the dose in the underlying tissues. While this is a satisfactory procedure for radiation protection, difficulties arise when the reported results are used to estimate the actual dose in tissue, and particularly the whole-body dose.

9. It is therefore not surprising that practice varies as to whether the results of personnel monitoring programmes are reported as exposures (R), absorbed doses (rad) or dose equivalents (rem). The dose equivalent is frequently used since it is in terms of this quantity that the International Commission on Radiological Protection (ICRP) expresses the maximum permissible doses for occupational exposure, thus taking account of differences in the biological effectiveness of different radiations. The dose equivalent (H) is the absorbed dose (D) expressed in rads multiplied by a quality factor (Q) determined from the linear energy transfer (LET ∞) of the radiation (22). However, in many instances it is not possible to know which quantity was originally determined, and the Committee has therefore decided, for the purposes of this report, to use the term "recorded dose", for want of a better term. In keeping with its previous practice, the Committee has adopted the procedure of using the rad as the unit for this quantity. However, in instances where the recorded dose may contain a significant component of high-LET radiation (such as neutron exposures), it becomes necessary to draw special attention to this fact.

10. With external monitoring there is seldom much information available about the actual doses received by the various tissues. Individual workers rarely wear more than one dosemeter, the exposure of which may or may not give a true indication of the doses received by the various parts of the body (1). However, when only a single dosemeter is used, it is frequently worn at the position of highest exposure, in which case the dose in more distant parts of the body will generally be lower than in the dosemeter. Exceptions to this may occur with localized high exposures of parts of the body, an extreme example of this being with narrow beams from x-ray crystallographic machines.

11. For various reasons, therefore, it is probable that the direct use of data about individual doses from personnel monitoring programmes will tend to overestimate population doses for the various tissues of interest, but, at the low levels currently involved, this is not considered to be a serious problem.

12. With personal monitoring for internal exposure the position is even more complex. In work places the ambient levels of radio-activity are usually maintained at low values, and therefore significant internal exposures of radiation workers seldom occur. Intakes of radio-activity occur, however, on occasion from minor mishaps or incidents, and monitoring procedures may thus often be discontinuous. Whilst they are entirely adequate to ensure compliance with prescribed intake limits, they may involve considerable uncertainty for dose estimates at the very low levels occurring. Available information suggests that when higher levels occur they are limited to very few workers. Exposure to tritium is, however, an exception, and appreciable whole-body doses frequently occur in workplaces where this nuclide is used. Another exception is the exposure of the lungs of workers engaged in underground uranium mining.

III. Results

13. The main function of this annex is to present estimates of the population dose resulting from occupational exposure to radiation. With a few exceptions information about population doses was not submitted to the Committee, so that estimates of the population dose had to be made from other available data. In addition, it was felt that it would be useful to present data on the numbers of radiation workers per thousand population for comparison with the 1962 report, on the distribution of dose in certain ranges and on the annual mean dose for various occupational categories.

A. The numbers of radiation workers

14. With the increasing use of radiation sources and radio-active substances it becomes increasingly difficult to define what is meant by "radiation workers". There is no clear border-line between the group of workers who are directly engaged in manipulating radiation sources and those workers who are less actively engaged in such work but who are nevertheless exposed to ionizing radiation in the course of their work. Often a "radiation worker" is merely a worker who might receive radiation doses of such magnitude that dose monitoring is justified (see paragraphs 15-17). Hence, the actual number of radiation workers in different countries may sometimes differ merely as the result of different administrative practices.

15. In the 1962 report the term "occupational exposure" was considered to apply to all activities involving exposure of individuals in the course of their work, regardless of whether or not they were directly engaged in radiation work. At that time it was customary, for radiation protection purposes, to make a distinction between individuals who were regularly, and those who were occasionally, exposed in the course of their work. In addition there was a large group of individuals, such as typists, cleaners, etc., who worked in radiation establishments, but who were not considered to be occupationally exposed to radiation. However, in 1966 the ICRP introduced (23) the concept of a single category of occupational exposure, namely, the radiation exposure received by any worker in the course of his work.

16. In its 1966 recommendations the ICRP also noted that for administrative purposes it was convenient to consider two conditions under which workers are exposed, namely, conditions such that the resulting doses might exceed three tenths of the annual dose limit, and conditions in which they are most unlikely to exceed this value. The ICRP recommended that personal monitoring and health supervision should be applied in the former case, but indicated that they were not generally required in the latter.

17. The anticipated result of this recommendation was that a considerable number of workers, employed under conditions such that their exposures were most unlikely to exceed three tenths of the dose limits, would no longer be subject to personal monitoring, and consequently would not be included in the records of monitoring programmes. In this case, unless steps had been taken to include information on this latter category, any use of data derived from personal monitoring programmes would underestimate the actual number of radiation workers. However, the impact

of the 1966 recommendation of ICRP has not been fully realized in practice and, in the words of one report (15), "it is difficult to advocate any radical pruning of the numbers of workers subjected to film or other forms of monitoring". Thus, it is not possible to say to what extent the reported numbers of monitored persons may underestimate the actual number of radiation workers.

18. Table 1 presents data on the numbers of radiation workers per thousand population in various countries. It will be seen that the total is approximately the same in most countries, a representative figure being between 1 and 2 per thousand, with a somewhat higher figure for the United States. The high value for Norway (2.7 per thousand) may be accounted for by the particularly large number of dentists and dental assistants in that country. It is not clear whether the figures for other countries include dental assistants or not. In general, the number of workers in the medical field has not changed since the time of the 1962 report, being still about 0.3-0.5 per thousand.

19. However, in industry there are indications (Australia, the German Democratic Republic, Sweden) that there has been a considerable increase over the previously reported value of about 0.06 per thousand. There has also been an increase in the reported number of workers in education and research.

B. The distribution of recorded doses in certain dose ranges

20. A number of countries supplied data on the distribution of recorded individual doses in certain dose ranges for various types of work. With the exception of exposures resulting from irradiation by tritium, ^{131}I and some bone-seeking nuclides, which will be dealt with later, all information about the doses relates to external exposures. It needs to be emphasized that the numbers of persons in the lowest dose ranges will depend on the numbers of workers supplied with personal dosemeters.

21. The recorded dose ranges varied somewhat, and for the purposes of this report the following ranges, in rads per year, have been selected: 0-0.5; 0.5-1.5; 1.5-5; >5.

22. Tables 2-10, showing the percentages of monitored workers in different dose ranges must be read with some caution since the numbers are dependent on the somewhat arbitrary selection of the group of "radiation workers" being monitored. For example, an increase in the monitoring programme would be expected to raise the percentage number in the lowest dose range and decrease the percentage number in the highest dose range.

23. Table 2 shows the percentages of monitored workers in the various ranges in five countries. It will be seen that most workers are reported as receiving less than 0.5 rad per year, and that very few receive recorded doses of more than five rads per year.[2] Data from Sweden (64) show that a large proportion of workers receive no detectable exposure in a year.

24. Tables 3 and 4 show the trend of exposure with time in Poland and New Zealand. In both countries it is seen that a considerable decrease in recorded dose has occurred. This is particularly evident in New Zealand, for which data covering a period of 16 years are available on monitoring films exposed to gamma rays and x rays above 150 kV. Table 4 shows the percentage of monitoring films exposed in selected ranges, and demonstrates the marked change that occurred between 1954 and 1958, which has been maintained since then.

25. A similar trend is shown in table 5, which illustrates the experience in the gynæcological department of a large Swedish medical centre in which radium is used extensively. Over the period 1961-1968 there was a marked shift of exposures towards the lower dose ranges, as a result of intensive efforts to reduce the irradiation of the staff.

26. Exposures of medical workers using radium tend to be higher than for those exposed to other radio-nuclides and x rays, as exemplified by data from the German Democratic Republic for 1966 (table 6).

27. Information was received from the United States about the results of film-badge monitoring of a sample of workers using radio-active materials (table 7). The recorded dose ranges differ slightly from those used previously but they confirm that, in general, the great majority of exposures lies in the lower dose ranges. Two significant exceptions may be noted: the first concerns the large percentages of waste-disposal workers with exposures in the high dose ranges, and the second shows the same trend, although to a much lesser extent, among industrial radiographers.

28. Information from India (table 8) also shows that most exposures are in the lowest range. However, in contrast with the data for the United States (table 7) workers in industry, and especially in reactor work, show a higher proportion of exposures in the range 0.5-5 rads.

29. Data about the exposure of atomic energy workers are shown in table 9. Most of the data refer to atomic energy research establishments, but the data from Canada's NPD reactor and from the United Kingdom are for workers in nuclear power stations. The figures from the United Kingdom are for seven nuclear power stations of the Central Electricity Generating Board.

30. An extensive review (14) of occupational exposure in the United Kingdom during the three-year period 1963-1965 confirms the observations made in other countries about the smallness of the doses received by most workers, 91-100 per cent of workers being reported as receiving less than 1.5 rads per year. Workers in medical radio-therapy, luminizing and industrial radiography received the highest doses, although less than 1 per cent of these received more than an average of five rads per year. However, a more recent analysis (2) has been made in the United Kingdom of the exposures of industrial radiographers working in factory conditions, and in the field (e.g., construction sites, gas pipelines). This showed that 5 per cent of factory radiographers and 11.5 per cent of site radiographers received doses greater than an average of five rads per year. For the period 1965-1970 the average annual recorded dose for factory radiographers was 0.9 rad, whereas for site radiography it was 2.7 rads.

[2] It should be pointed out that under the ICRP recommendations, a worker may exceptionally receive a whole-body dose up to 12 rems in a single year provided that his average exposure does not exceed 5 rems per year (23).

The analysis concludes that the standard of radiological protection for workers engaged in site radiography is significantly lower than for workers employed in factory conditions. Nevertheless, the good results obtained by some firms in both groups suggest that, if the necessary precautions are taken, the process of industrial radiography can be carried on without workers receiving doses greater than those permitted by the national regulations.

31. Observations over a period of six years (1962-1967) made in the Federal Republic of Germany (8) showed that the percentage of workers with exposures over five rads was nearly constant from year to year, and mostly below 1 per cent, although the total number of workers doubled in the same period of time.

32. In Japan, in contrast with other countries, exposures of medical workers in 1968 were rather greater in the higher dose ranges, but very few recorded doses exceeded five rads (table 10).

C. The mean annual dose by type of work

33. Table 11 shows the mean annual recorded dose in rads for monitored workers in various types of work involving external exposure. In some cases the values shown are those reported by the country in question. In the remaining cases no value was given and it had to be estimated. For this purpose it was necessary to select a representative dose from the information supplied about the numbers of workers in various dose ranges.

34. The selection of an appropriate value for the mean annual dose for the range 0-0.5 rad has to take account of the well-known skewed distribution within this range. The value of the mean dose will depend critically on how many more-or-less unexposed workers were actually monitored. A Swedish analysis (64) shows that, for persons wearing monitoring films that were all reported as being exposed below the practical threshold value, the mean annual recorded dose was about 20 millirads. The mean annual recorded dose when films were reported as falling in the range 0.05-0.5 rad was about 150 millirads. For the purposes of this report, therefore, the value of 0.1 rad was selected as the mean dose for the reported range 0-0.5 rad. The use of this value probably results in an over-estimate of the dose contribution from this range; for example, the use of this value, if applied to the data in table 2, results in contributions from the recorded dose range 0-0.5 rad of about 50 per cent to the total calculated man-rads in each category of work, the actual proportion varying from 12 to 83 per cent. Because the calculated mean doses are generally low in relation to the dose limits, this is not considered to be a serious drawback.

35. For the ranges 0.5-1.5 and 1.5-5 rads, representative values were selected at one rad and three rads, respectively. The Swedish data referred to in the previous paragraph gave values for these ranges of 0.8 rad and 2.5 rads, respectively. For recorded doses greater than five rads, representative values were chosen at the arithmetic mean when ranges were given, or were arbitrarily allotted the value of seven rads when the only information was that there were exposures greater than five rads.

36. A fairly consistent pattern emerges from table 11, indicating that the mean recorded dose in medical work and in industry usually lies between about 0.2 and 0.6 rad per year, and that in other work the dose is lower. Data from Australia, New Zealand and the United Kingdom show higher mean doses in medical radio-therapy than in medical radio-diagnosis, this apparently being mainly caused by exposure to sealed radio-active sources. This is confirmed by data from the German Democratic Republic (7) from which it can be calculated that medical workers exposed to radium and radio-active cobalt sources received an annual mean dose of 0.79 rad, while those working with x ray machines (diagnostic and therapy) received 0.13 rad.

37. Data concerning certain hospitals in Paris for the year 1971 (51) show that in spite of the introduction of up-to-date equipment, exposures in radiological departments were still far from negligible, over 1 per cent of workers receiving more than 2 rads per year. In certain specialized radiological work up to 10 per cent of the workers received more than 2 rads per year; this particularly applied to angiography and to radiological procedures conducted during surgery and brachytherapy. The increasing use of medical radiology, and in particular, its use during surgery and in specialized procedures such as angiography, emphasizes the importance of adequate protection for all those involved in this work.

38. Swedish data (65) show that medical workers exposed to x rays (unspecified as to whether diagnostic or therapeutic) received a mean recorded dose of 0.11 rad per year and that those using radio-nuclides received 0.34 rad. A point of interest is the relative contribution to the doses received by radio-isotope workers from sealed and unsealed sources. More than 90 per cent of the mean recorded doses received by this group was from exposure to brachytherapy sources (64). Reference has already been made (paragraph 25) to the exposures in a large Swedish medical centre using radium (38). From data summarized in table 5 it was calculated that the annual mean recorded dose to workers in this centre was steadily reduced from a value of about two rads in 1961 to less than one rad in 1968.

39. The mean annual dose to the trunks of veterinary workers, as reported in the United Kingdom for 1964 (14) was 0.24 rad. This can be compared with an assessment of the dose in 1969 (50): in this study a special evaluation of low doses was made, and the mean annual doses were estimated to be 0.04 rad in women and 0.07 rad in men.

40. The data from New Zealand, which are presented in table 4, have been used to estimate the mean exposure from gamma rays and x rays above 150 kV. In 1954 the mean exposure of monitoring films was 2.4 roentgens, and by 1958 it had been reduced to 0.4 roentgen. Since 1958 the mean exposure has remained steady, at just below 0.4 roentgen.

41. The information presented in table 7, showing the distribution of recorded dose in the United States, can be used to calculate mean recorded doses in the various types of work. These show general agreement with the results shown in table 11, but in the case of waste-disposal workers the annual mean recorded dose was 1.84 rads. Industrial radiographers had a mean recorded dose of 0.50 rad (54).

42. Amongst other industrial workers, luminizers in the United Kingdom were reported to have received an average recorded dose of 0.59 rad in 1964; these luminizers worked at that time mainly with radium-

activated luminous compound "in rather primitive working conditions" (14). Luminizing is now tending to be done with tritium- rather than radium-activated compounds, with a consequent reduction in external exposure. The occupational exposures from tritium luminizing are from internal radiation and are discussed in paragraphs 51 and 52.

43. Information about the doses received by atomic energy workers, whether in research establishments or in nuclear power stations, are not generally available in the scientific literature. The data included in this report were made specially available to the Committee, and in some cases the original data had to be changed into a form suitable for the Committee's purposes. The annual mean recorded doses of workers in research atomic energy establishments varied considerably, ranging from 0.06 rad in Israel to 0.69 rad in the United Kingdom. The latter figure is for workers employed by the United Kingdom Atomic Energy Authority. Among this group, those working on nuclear-fuel reprocessing were reported as receiving a mean annual dose of 1.5 rads (41). A value of 0.11 rad per year in 1968 was reported from the Oak Ridge National Laboratory in the United States (47).

44. Data were provided on doses received by workers in seven nuclear power stations operated by the Central Electricity Generating Board in the United Kingdom (49). In 1969 these ranged from mean recorded doses of 0.84 rad in the oldest station to 0.17 rad in the newest. In the same year, the mean recorded dose in three nuclear power stations in the United States ranged from 0.6 to 1.3 rads (54).

45. Information about a number of nuclear power stations makes it possible to calculate the ratio of total staff dose to output of electricity, expressed as man-rads per megawatt-year of electricity. This quantity, whilst not of importance for the individual workers, is of relevance to the total dose incurred by the population. The results are shown in table 12. These results only apply to the doses received by workers within nuclear power stations; however, in the case of the British nuclear power programme an estimate can also be made of the total occupational dose contributed at present by the reprocessing of the nuclear fuel (including waste management) used in the power reactors. The available data indicate that, for the two years 1968-1969, the occupational exposures contributed by fuel reprocessing (41) and by work in the nuclear power stations (49) were:

Fuel reprocessing	1.6 man-rads per megawatt-year
Power stations	0.7 man-rad per megawatt-year
Total	2.3 man-rads per megawatt-year

46. Only limited information is so far available on the dose related to electrical output, but the data indicate that, at the present time, for a fairly-well-established nuclear power programme, electricity can be produced at a rate of two or three man-rads per megawatt-year, of which the dose contributed by fuel reprocessing appears to form the major part. Improved technology, and the trend towards the construction of power reactors with greater electrical output, in which the staff exposures are not likely to raise proportionately, are expected to result in lower values of man-rads per megawatt-year, as indicated in table 12. Technical developments in reprocessing plants which are likely to be greatly expanded in the next decades are expected to result in a reduction of the total occupational dose per megawatt-year. In the United Kingdom, for instance, nuclear power generation is expected to reach about 90 GW y (46) by the year 2000 and the contribution of occupational exposure to the total population dose is still likely to be relatively small compared with the natural radiation background (population doses from environmental contamination by nuclear power stations are discussed in annex A of this report).

47. During the first six months of 1971 the exposure of the crew of the N.S. *Otto Hahn* was at the rate of 0.5 man-rad per megawatt-year (thermal) (71): this cannot be compared directly with the estimates of dose per megawatt-year for nuclear power stations for which the power output is expressed as megawatt-year (electrical).

48. The data that have so far been referred to come mainly from the more developed countries, in which, as has been seen, average annual doses are now usually much less than one rad. A report from Pakistan (43) on 600 persons monitored by means of film badges, representing 20-30 per cent of all radiation workers in that country, showed average weekly exposures of about 34 milliroentgens, corresponding to approximately 1.5 rads per year. Five per cent of the films were reported as showing exposures greater than 100 milliroentgens per week, or five rads per year. The Pakistani report states that in organizations having a "local radiation-safety facility" the average weekly dose was 10 milliroentgens and that 2 per cent of the films exceeded 100 milliroentgens per week; the report does not state what proportion of workers in these organizations were supplied with film badges.

49. All the preceding results relate to external exposures. Data are available from Canada (56) on the whole-body doses from tritium uptake by workers at the Chalk River Nuclear Laboratories, where tritium monitoring is performed only when it is suspected that a tritium intake has occurred. Among individuals monitored in this way the average recorded whole-body dose in 1968 was 0.24 rad. The dose from the uptake of tritium may be compared with the dose from external gamma radiation, which averaged 0.70 rad among those workers receiving detectable exposures.

50. At the Canadian heavy-water reactors, occupational exposure to tritium accounts for 12-26 per cent of the dose (table 12).

51. Estimates of the dose received by workers using tritium in industry have also been reported in the United Kingdom (33). These workers were employed in the luminous-paint industry, and in filling gas in capsules used as self-luminous warning signs etc. The doses received by the workers were derived from the measured concentration of tritiated water in their urine. Table 13 shows the distribution of doses reported in the original paper, and a calculated value of the mean doses for the years 1963-1969.

52. Data on annual mean doses are also available for luminizers using tritium in France and the Federal Republic of Germany. A group of French workers, numbering from 15 to 35, was reported to have received mean doses of 0.17-0.86 rad in the four years 1968-1971 (51). The results of a survey of luminizers in the Federal Republic of Germany are shown in table 14. It will be seen that over the period 1962-1969 there was a steady improvement, due to an energetic programme of radiation protection. Tritium-energized luminous paint was introduced to reduce

population exposures from radium in wrist watches. Its increasing use in consumer products, and the problems of monitoring the internal exposures of workers, emphasize the need for stringent control of its use in industry, especially after the recent publication of two fatalities among tritium workers in Germany (61).

53. Contamination by tritium from watches at wholesale importers, retailers and refiners has been reported. A dose of 0.5 rad in a year was estimated to have been received by an individual working in a firm of wholesale importers which handled 200 Ci per year and which had poor ventilation. Contamination was negligible in retail establishments. Watch repair-men and refiners had negligible internal contamination (6).

54. Several investigations of medical and paramedical personnel working with radio-nuclides have been reviewed (62). Individuals working with iodine radio-nuclides received higher doses than those working with other radio-nuclides (^{99m}Tc, ^{133}Xe, ^{137}Cs, ^{74}As, ^{22}Na, ^{68}Ge); 70 per cent of individuals working with ^{125}I showed contamination of their thyroid glands, with an average activity of 5 nanocuries, and a maximum level of 20 nanocuries. The degree of contamination appeared to be related to the quantity of material handled, and not to the professional category of the worker. Only 15 per cent of persons working with ^{131}I showed the presence of the nuclide in their thyroid glands, the maximum amount being four nanocuries. These lower levels with ^{131}I were attributed to the availability of pre-packaged forms of this nuclide for diagnostic purposes, improved procedures for radio-nuclide handling and administration, and increased emphasis on radiological protection.

55. Data were submitted from Argentina (3) on the dose to the thyroid gland among workers at the Comisión Nacional de Energía Atómica involved in the production of ^{131}I and of compounds labelled with this nuclide. In 1969 57 per cent of the workers accumulated less than 0.6 rad, 25 per cent received 0.6-3 rads, 3 per cent received 3-6 rads, and 15 per cent received a dose in the 6-30 rads range. None had a total dose greater than 30 rads, the maximum permissible dose for the thyroid gland.

56. At the same establishment 93.5 per cent of workers exposed to bone-seeking radio-active materials (enriched uranium and ^{32}P) had an annual intake, by inhalation, of less than 2 per cent of the maximum permissible, and 6.5 per cent had intakes between 2 and 10 per cent of the annual maximum permissible (3).

57. A special case of internal exposure involving also some workers who are not usually recognized as radiation workers, is the exposure to radon and its radio-active daughter products in underground mines. Inhalation of radon and its daughter products in various types of underground mines has been reported, particularly in the mining of uranium (20, 68), thorium (45), fluorspar (13), tin (15) and hæmatite (15). In some uranium mines considerable practical difficulties have been experienced in keeping the concentrations of radon below currently recommended limits; for example, in Argentina in 1970, 24 per cent of about 150 uranium miners were exposed to an integrated concentration of "equilibrium equivalent radon" greater than 60 nCi h l^{-1} (3) which corresponds to the maximum permissible concentration in air recommended by ICRP, inhaled for 2,000 hours. In Swedish metal mines in 1969-1970 40 per cent of 4.700 workers were exposed to average concentrations greater than 30 pCi l^{-1} (66).

58. In some mines where men were exposed to high concentrations of radon and its daughter products an increased incidence of lung cancer has been reported (40). An increased incidence of lung cancer has also been reported in fluorspar (13) and hæmatite (15) mines. Because of the difficulty in assessing lung dose from inhalation of radon, no attempt has been made here to assess a population dose from occupational exposure in mines. Estimates of the risk of developing lung cancer as a result of exposure to radon and its daughter products are discussed in annex H of this report.

59. The risk of cancer in underground miners has presented one of the major problems in radiation protection. However, during recent years there has been a marked improvement in working conditions in mines, with a subsequent lowering of the exposure to radon and its daughter products.

D. The population dose resulting from occupational exposure

60. The Committee's 1962 report contained estimates of the genetically-significant doses (GSD) resulting from occupational exposure, and it was concluded that 0.5 millirem represented an upper limit to those doses; this conclusion was based on data from three countries.

61. The policy adopted by the Committee for calculating average population doses is described in detail in annex A, paragraphs 5 to 13.

62. To make a precise estimate of the GSD, however, requires knowledge of the actual gonad doses, the size of the groups receiving such doses, and the child expectancy of such groups. Only Japan and New Zealand have used these factors, and both conclude that the total value of the GSD was 0.07 millirad in the particular year studied. For New Zealand an estimate was also made of the corresponding *per caput* dose to the whole population, which was approximately twice the value of the GSD. The contributions to the GSD are shown in table 15.

63. For countries where the required data are not available, the table also shows over-all population doses. In one case (Australia) allowance was made for the dose actually received by the gonads and for the ages of the exposed individuals. The remaining population doses were simply determined as a *per caput* dose to the entire population of the particular country. Since the latter doses were obtained from personal monitoring, and did not allow for depth dose or child expectancy, they are likely to be over-estimates. Nevertheless, the available data strongly indicate that the population dose is unlikely to exceed 0.5 millirad per year, and that in many cases the actual value may be less than 0.1 millirad per year.

IV. Some special problems

64. In addition to the occupational exposures that have been considered in this chapter there are a number of categories of radiation work that may present special problems for radiation protection. These include radiation exposure of television maintenance men; a survey concludes that "occupational x-radiation exposure of television repair-men and assemblers is

virtually non-existent" (59). This conclusion is supported by a study of the exposure of television repair shops in Baltimore, United States, in which it was found that negligible doses were received (74). A survey of 30 aircraft-instrument repair shops in the United States revealed many cases of significant radium contamination resulting from repair and stripping operations on radium luminous dials (60).

65. Additional categories of radiation work about which it would be valuable to have information or associated radiation doses include exposure of radar operators to x rays emitted from klystrons and magnetrons; exposures in educational institutions, especially in schools for x-ray technologists; exposures of transportation workers; exposures of aircraft maintenance workers; and exposures of radio-pharmaceutical manufacturers.

66. Consideration is given in annex A of this report to the exposure of the crews of supersonic aircraft. The total galactic cosmic-ray dose equivalent rate at supersonic altitudes is estimated to be about 1 mrem h^{-1}, which is approximately double the rate at subsonic altitudes. The annual dose to be received by crews of supersonic aircraft might be about 1 rem per year, depending on the length of time spent at supersonic altitudes. This may be compared with the exposure of crews in current subsonic jet aircraft, who are estimated (42) to receive about 0.5 rem per year. In addition, crews of supersonic aircraft may be exposed to solar flare radiation, but it is expected that appropriate measures will ensure that the dose contribution from this source will be small.

67. Astronauts in space can be exposed to a fairly constant background of 30-50 millirads per day from primary galactic radiation and its secondaries (34). In addition, they can also be exposed to periodic solar flares and magnetically-trapped radiations, in which the dose rates have been estimated to vary from a fraction of a rad per hour up to 20 rads per hour, and the duration from minutes to days (34). The total dose for space missions up to six months' duration has been estimated to range up to 2,000 rads, depending upon the phase of the solar cycle (34).

V. Accidents

68. Occasionally, radiation injuries occur in persons occupationally exposed to ionizing radiation. These can usually be attributed to severe over-exposures resulting from failures of safety procedures or from carelessness. A number of injuries have been reported in x-ray analytical work (37), and in industrial radiography (4, 5).

69. In addition to the few accidents that have resulted in radiation injury, there has been a number of incidents, some of which have involved exposures in excess of currently accepted limits, but which have not resulted in injury (11). A survey of lost-time accidents in operations of the United States Atomic Energy Commission and its associates over the period 1943-1970 (73) showed that during that period over 4 10^9 man-hours were worked. Lost-time injuries attributable to all causes amounted to 17,934, of which 9,147 occurred in AEC operations. Only 38 of the 9,147 lost-time injuries were caused by nuclear radiation; these included three fatalities shortly after exposures received as a result of criticality accidents in the early days of atomic energy (three additional deaths caused by the explosion of the SL-1 reactor not being included). A report (76) has reviewed 400 incidents involving radium, most of which involved loss of radium sources from medical establishments, with approximately one third of the sources not being recovered. No injuries were reported in this review. The total contribution to the population dose from all these accidents is likely to have been very small.

70. Two reports from Thailand emphasize the hazards of the hand-held fluoroscope. A prolonged exposure (about 30 minutes) with a poorly protected hand-held fluoroscope resulted in injury to a hand of an examining physician and to the foot of his patient (57). The absorbed dose in the skin of the patient's foot was estimated to be greater than 6,000 rads. Another instance of severe injury occurred in the hand of a physician using a mobile x-ray machine and a hand-held fluoroscope (58). The dose to the physician's hand was estimated to be between 3,000 and 6,000 rads. No injury was reported as developing in the patient, in whom the dose was calculated to be 10-15 per cent of that received by the physician. An investigation has revealed the existence of 30 additional hand-held fluoroscopes in the same country.

VI. Summary

71. Data assembled since the Committee's 1962 report indicate that the total number of radiation workers has remained at about 1-2 per thousand of total population.

72. The majority of radiation workers receive very low exposures, and very few exceed the recommended maximum permissible doses recommended by the International Commission on Radiological Protection. The mean annual recorded dose for most types of radiation worker lies in the range of 0.2-0.6 rad per year. In particular types of work, notably industrial radiography and medical work involving the use of radium, higher exposures have been reported. Mean annual recorded doses as high as 2.7 rads per year have been reported for industrial radiographers working on site radiography.

73. The integrated dose among occupationally-exposed persons involved in the production of electricity by nuclear power is at present about 2-3 man-rads per megawatt-year, most of the dose apparently being received during the reprocessing of nuclear fuel. Improved technology is expected to result in lower values of man-rads per megawatt-year.

74. The genetically-significant dose from occupational exposure has been estimated in two countries to be 0.07 millirad in a year, with a corresponding *per caput* dose of about twice this value. Other estimates of the *per caput* dose range as high as 0.8 millirad in a year. This may be compared with the 1962 estimate of 0.5 millirem as being the likely upper limit of the genetically-significant dose from occupational exposure.

75. Over-exposures and injuries are now extremely rare in most kinds of radiation work. There are, however, several types of radiation work in which accidental high exposures and injuries are still not uncommon. Chief among these are industrial radiography and x-ray crystallography, in which careless operating procedures are nearly always the cause of reported injuries. The use of the hand-held fluoro-

scope for the examination of patients has led to a number of reported injuries, both in patients and in the examining physicians.

76. Difficulty is being experienced in a number of underground mines (and, in particular, uranium mines) in maintaining the inhalation exposures of miners below currently recommended limits. Abnormally high incidences of lung cancer have been reported in various groups of underground miners exposed to levels much above those recommended by the International Commission on Radiological Protection. Much effort is currently being put into reducing the exposures of underground miners.

77. There has also been some initial difficulty in the luminizing industry, when there has been a change from the use of radium to tritium in the luminous compound, in preventing excessive uptake of tritium by the workers. Experience shows that special care needs to be taken if the exposures of the staff are to be kept well below the recommended limits.

TABLE 1. NUMBER OF RADIATION WORKERS PER THOUSAND POPULATION

	Type of work										
	Medical	*Diagnosis*	*Therapy*	*Dental*	*Chiro-practic*	*Veter-inary*	*Indus-trial*	*Research and education*	*Atomic energy*	*Total*	*Reference*
Argentina 1969									0.08		3
Australia 1966-1967		0.41	0.11	0.40	0.02	0.02	0.14	0.25	0.08	1.5	67
Belgium 1968	0.4			0.01			0.1	0.2	0.02	0.7	18
Denmark 1968	0.8			0.2		0.03	0.03	0.2	0.2	1.5	17
Federal Republic of Germany 1969	0.14						0.09	0.12	0.07	0.4[a]	9
Finland 1967				0.27						0.9	69
France 1969-1970	0.85			0.30			0.32	0.11	0.49[b]	2.1	51
German Democratic Republic 1966	0.9						0.2	——0.2——		1.5	7
Italy 1966		0.27	0.06	0.20		<0.01	0.04	0.05	0.07	0.7	52
Japan 1968			——0.28——				0.06	0.05	0.02	0.4	19
Netherlands 1969			——0.7[c]——				0.1		0.02	0.8	75
New Zealand 1969		0.32	0.10	0.55	0.04	0.07	0.05	0.13	0	1.3	48
Norway 1968		0.51	0.05	1.8[d]		0.01	0.08	0.12	0.19	2.7	30
Poland 1966	0.38						0.07	0.07		0.5	39
Sweden 1968	0.5			1.0		0.01	0.13	0.16	0.15	2	36
Thailand 1970										<0.1	58
United Kingdom 1968-1969						0.07			0.36[b]		41, 49, 50
United States 1970	1.33			0.87				1.55		3.7	42

[a] Does not include x-ray workers.
[b] Includes nuclear power stations.
[c] Includes research and education.
[d] Includes a value of 0.8 for dental assistants.

TABLE 2. PERCENTAGE OF WORKERS IN RECORDED DOSE RANGES

Dose range (rad y^{-1})	*Czechoslovakia, 1966 (12)*		*Federal Republic of Germany, 1969 (9)*			*Finland, 1967 (69)*		*German Democratic Republic 1966 (7)*			*Poland[a] 1966 (32)*		
	Medical	*Industry*	*Medical*	*Industry*	*University and research*	*Medical and research*	*Industry*	*Medical*	*Industry*	*University and research*	*Medical*	*Industry*	*Research and other*
0-0.5	87.2	73.7	88.9	87.3	89.0	89.8	99.0	96.2	97.2	92.0	78.8	94.7	95.5
0.5-1.5	9.8	14.8	10.8	12.4	10.4	7.2	0.5	2.5	2.1	4.6	14.4	3.9	3.3
1.5-5	2.2	10.4	0.2	0.3	0.4	3.0	0.5	1.3	0.7	3.0	6.3	1.4	1.2
>5	0.7	1.0								0.4	0.4		

[a] These data refer only to persons engaged in work with radio-nuclides.

TABLE 3. PERCENTAGE OF POLISH WORKERS IN RECORDED DOSE RANGES (26-28)

Dose range (rad y⁻¹)	*1966*	*1967*	*1968*	*1969*
<0.1	85.5	89.5	91.1	92.0
0.1-0.4	9.3	7.0	6.3	5.6
0.4-1.2	3.3	2.2	2.0	1.7
1.2-5	1.3	0.9	0.5	0.5
>5	0.7	0.4	0.2	0.1

TABLE 4. PERCENTAGE OF MONITORING FILMS EXPOSED[a] IN SELECTED EXPOSURE RANGES IN NEW ZEALAND (55)

Exposure range (R y⁻¹)	*1954*	*1958*	*1963*	*1969*
0-0.5	24.0	84.0	86.0	88.8
0.5-1.5	30.0	10.8	9.5	6.4
1.5-5	29.5	4.0	3.6	3.2
>5	16.5	1.2	0.9	1.6

[a] Exposure to gamma rays and to x rays over 150 kV.

TABLE 5. PERCENTAGE OF WORKERS IN RECORDED DOSE RANGES (GYNÆCOLOGY DEPARTMENT, RADIUMHEMMET, STOCKHOLM, SWEDEN) (38)

Dose range (rad y⁻¹)	*1961*	*1962*	*1963*	*1964*	*1965*	*1966*	*1967*	*1968*
⩽1	51.6	60.4	62.7	69.4	69.3	64.7	77.2	80.2
1-2	17.2	12.1	15.5	6.9	9.3	20.6	15.3	17.0
2-5	19.4	17.4	17.6	17.5	17.3	14.0	7.4	2.8
>5	11.8	10.1	4.2	6.3	4.0	0.7	0	0

TABLE 6. PERCENTAGE OF MEDICAL RADIATION WORKERS IN RECORDED DOSE RANGES (GERMAN DEMOCRATIC REPUBLIC, 1966) (7)

Dose range (rad y⁻¹)	*X ray*	*Radium*	*Radio-nuclides other than radium*
0-0.5	98.1	64.1	86.8
0.5-1.5	1.4	19.3	7.4
1.5-5	0.4	15.7	5.4
>5	0.1	0.8	0

TABLE 7. PERCENTAGE OF WORKERS IN RECORDED DOSE RANGES IN LICENSED INSTALLATIONS[a] (United States, 1968) (54)

Dose range (rad y⁻¹)	*Academic*	*Medical*	*Major processor*	*Industry general*	*Industry radiography*	*Waste disposal*	*Fuel processing and reprocessing*	*Power and research reactors*	*All other*
0-0.5	96.5	87.9	88.0	91.7	75.0	46.2	86.1	95.7	94.6
0.5-1	2.1	7.1	4.0	3.4	10.5	6.6	5.4	2.4	3.4
1-5	1.4	4.7	6.8	4.7	14.0	33.8	7.4	1.7	1.8
>5	0	0.2	1.2	0.2	0.5	13.3	0.1	0.2	0.2

[a] The data in this table apply to facilities licensed under the United States Atomic Energy Act, and do not include those workers exposed to machine-produced radiation exclusively.

TABLE 8. PERCENTAGE OF WORKERS IN RECORDED DOSE RANGES (INDIA, 1969) (31)

Dose range (rad y⁻¹)	*Medical*	*Industry*	*Research and education*	*Fuel reprocessing*	*Waste disposal*	*Power and research reactors*
0-0.5	92.1	77.6	97.4	93.4	89.1	68.9
0.5-1.5	5.4	15.7	1.8	5.4	8.1	16.6
1.5-5	2.2	4.7	0.6	1.2	2.7	14.4
>5	0.4	1.9	0.2	0	0	0.1

TABLE 9. PERCENTAGE OF ATOMIC ENERGY WORKERS IN RECORDED DOSE RANGES

(All external, except tritium)

Dose range (rad y^{-1})	Argentina, CNEA, 1970-1971 (3)	Canada, AECL, 1968 (56)	Canada,[a] NPD, 1969 (77)		France, CEA (25) 1968	India, BARC (31), 1969	United Kingdom,[b] CEGB (49), 1968	United States, ORNL (47), 1968
			External	Tritium				
0-0.5	98.4	88.6	86.4	84.4	97.6	75.1	75.4	93.8
0.5-1	1.1							3.6
0.5-1.5		7.0	10.3	11.8	2.2	14.0	22.2	
1-5	0.5							2.6
1.5-5		4.4	3.3	3.8	0.2	10.4	2.5	
>5	0	0	0	0	0.01	0.4	0	0

[a] Nuclear power demonstration station.

[b] Seven nuclear power stations.

TABLE 10. PERCENTAGE OF JAPANESE WORKERS IN RECORDED DOSE RANGES (1968) (19)

Dose range (rad y^{-1})	Medical	Industrial	Research and education	Atomic energy
0-0.5	84.3	92.8	98.2	96.1
0.5-1	9.4	3.4	1.1	2.5
1-5	5.9	3.3	0.6	1.4
>5	0.3	0.4	0.1	0

TABLE 11. MEAN ANNUAL RECORDED DOSE (rad) BY TYPE OF WORK (EXTERNAL EXPOSURE)

	Type of work									
	Medical	Diagnosis	Therapy	Dental	Chiropractic	Veterinary	Industrial	Research and education	Atomic energy	Reference
Australia 1966-1967		0.19	0.34	0.02	0.03	0.07	0.25	0.07	0.13 (1969)	67
Belgium 1968	0.29			0.08			0.66	0.48	0.32	18
Brazil 1969	0.23						0.42	0.16	0.11	10
Czechoslovakia[d] 1966	0.34						0.62			12
Denmark[d] 1968	0.18			0.005		0.03	0.36	0.05	0.07	17
Federal Republic of Germany 1969	0.31						0.37[a]	0.34[a]		9
Finland[d] 1967							0.21			69
France 1969-1970				0.075			0.11	0.03		51
German Democratic Republic[d] 1966	0.17						0.15	0.26		7
India[d] 1969	0.21						0.62	0.06	0.49	31
Israel 1969	0.07			0.07			0.08	0.04	0.06	16
Italy 1966	——0.20——						0.08			52
Japan 1968	0.38						0.29	0.09	0.13	19
Netherlands 1969							0.40		0.27	75
New Zealand[d] 1969		0.08	0.34	0.07	0.09	0.06	0.42	0.16		48
Poland[d] 1966	0.44						0.18	0.17		39
Sweden 1968	0.15						0.10	0.02	0.10	64
Thailand 1969	0.33[b]						——0.86[c]——		0.28	58
United Kingdom 1964		0.35	0.49	0.27		0.24[e]	0.30–0.59		0.69[d] (1969)	14 41
United States[d] 1969-1970	0.34			0.12			——0.16——			70

[a] Includes atomic energy.

[b] Including dental.

[c] Including medical therapy.

[d] Values calculated by the Committee.

[e] But see special estimate referred to in paragraph 39.

TABLE 12. RECORDED STAFF DOSE IN RELATION TO ELECTRICAL OUTPUT FOR SELECTED NUCLEAR POWER REACTORS

Reactor	Reactor type	Rated power (12) (MW(e))	Years surveyed	Total electrical output (MW y)	Total staff dose (man-rads)	Man-rads per MW(e) y	Notes	Reference
Berkeley (United Kingdom) ..	GCR	276	1965–1969	1,401	2,027	1.4	Annual range 1.4-1.5 man-rad per MW y	49
Bradwell (United Kingdom) ..	GCR	300	1965–1969	1,436	1,269	0.9	Annual range 0.8-1.2 man-rad per MW y	49
Chinon 1, 2, 3 (France)	GCR	750	1962–1969	1,059	647	0.6	Man-rads apply to reactor staff only	21, 25
Dungeness (United Kingdom).	GCR	550	1965–1969	1,803	915	0.5	Annual range 0.3-0.8 man-rad per MW y	49
Hinkley Point (United Kingdom)	GCR	500	1965–1969	2,245	1,526	0.7	Annual range 0.6-0.8 man-rad per MW y	49
Latina (Italy)	GCR	200	1962–1969	965	590	0.6	Man-rads include doses received during refuelling and in large maintenance operations	21, 52
Marcoule (G-2, G-3) (France)	GCR	80	1958–1969	571	219	0.4	Man-rads apply to reactor staff only	21, 25
Oldbury (United Kingdom)..	GCR	600	1968–1969	624	156	0.2	Annual range 0.2-0.3 man-rad per MW y	49
Sizewell (United Kingdom) ..	GCR	580	1965–1969	1,423	360	0.3	Annual range 0.3-2.1 man-rad per MW y	49
Tokai (Japco-1) (Japan)	GCR	160	1965–1969	318	703	2.2		21, 44
Trawsfynydd (United Kingdom)	GCR	500	1965–1969	1,564	653	0.4	Annual range 0.3-0.9 man-rad per MW y	49
Indian Point (United States)..	PWR	265	1962–1969	1,033	1,386	1.3	Annual range 0.5-5.3 man-rad per MW y	53
Shippingport (United States) .	PWR	90	1965–1969	255	893	3.5	Annual range 1.0-8.7 man-rad per MW y	54
Trino Vercellese (Italy)	PWR	247	1964–1969	386	250	0.6	Man-rads include doses received during refuelling and in large maintenance operations	21, 52
Big Rock Point (United States)	BWR	70	1962–1970	305	1,217	4.0		63
Dresden (United States)	BWR	200	1960–1970	1,223	2,038	1.7	Annual range 0.8-4.0 man-rad per MW y	35
Garigliano (Italy)	BWR	150	1963–1969	645	750	1.2	Man-rads include doses received during refuelling and in large maintenance operations	21, 52
N Reactor (United States) ..	LWGR	790	1966-1969	1,248	1,446	1.2	Annual range 0.8-3.7 man-rad per MW y	21, 54
Douglas Point (Canada)	PHWR	208	1967–1969	155	1,386	8.9	Tritium contributes 12 per cent of dose	21, 77
Pickering 1, 2 (Canada)	PHWR	1,080	1971	338	198	0.6	Tritium contributes 26 per cent of dose	77

TABLE 13. PERCENTAGE OF WORKERS USING TRITIUM IN RECORDED DOSE RANGES (UNITED KINGDOM) (33)

Year	Workers monitored	<0.1 rad	0.1-1.5 rad	1.5-5 rad	>5 rad	Mean dose rad
1963	43	62.8	34.9	2.3	0	0.38
1964	56	51.8	44.6	3.6	0	0.58
1965	47	61.7	38.3	0	0	0.34
1966	42	19.0	71.4	11.9	0	0.93
1967	56	39.3	58.9	0	0	0.49
1968	56	41.1	58.9	0	0	0.49
1969	82	31.7	59.8	6.1	2.4[a]	1.43

[a] Two individuals, with doses of 7 rads and 55 rads.

TABLE 14. PERCENTAGE OF LUMINIZERS USING TRITIUM, IN RECORDED DOSE RANGES (FEDERAL REPUBLIC OF GERMANY) (29)

Year	*No. of supervised persons*	*<0.1 rad*	*0.1-1.5 rad*	*1.5-5 rad*	*>5 rad*	*Mean dose rad*
1962	1	0	0	0	100	88
1963	2	0	0	0	100	44
1964	4	0	25.0	0	75.0	8
1965	18	28.7	66.5	5.4	0	0.69
1966	108	34.3	36.1	16.6	13.0	0.87
1967	89	33.7	58.4	7.9	0	0.41
1968	108	28.7	52.7	16.7	1.9	0.49
1969	99	26.3	61.6	11.1	1.0	0.39

TABLE 15. CONTRIBUTIONS TO THE POPULATION DOSE (mrad y^{-1})
(*All* per caput *doses except Japan and New Zealand*)

	Type of work										
	Medical	*Diagnosis*	*Therapy*	*Dental*	*Chiro-practic*	*Veter-inary*	*Indus-trial*	*Research and education*	*Atomic energy*	*Total*	*Refer-ence*
Australia 1966-1967										0.1	67
Federal Republic of Germany 1969	0.04						0.05[a]	0.05[a]		0.14	9
Finland 1967	0.14						0.01			0.15	69
German Democratic Republic 1966										0.2	7
Israel 1969										0.07	16
Japan[b] 1968	0.044						0.024	0.001	0.005	0.07	19
New Zealand[b] 1969		0.016	0.022	0.017	0.002	0.003	0.009	0.006		0.07	48
Norway 1968										0.05	30
Poland 1966										0.01	39
Sweden 1968	0.07						0.01	0.004	0.02	0.1	64
United Kingdom 1968-1969									0.23[c]		41, 49
United States 1970	0.4			0.1			——	0.3	——	0.8	70

[a] Includes atomic energy.
[b] Calculated as genetically-significant dose.
[c] UKAEA (1969): 0.20; CEGB (1968): 0.03.

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