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THE NEED FOR A COORDINATED INTERNATIONAL ASSESSMENT OF THE RADON PROBLEM

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1. The radon problem - an issue of growing awareness

Radon is a natural pollutant which has been part of the human environment through all stages of evolution. However, the level of Rn-exposure has undergone various "technological enhancements" from the pre-historic days of taking up a habitat inside a cave dwelling, to the present day energy-efficient dwellings with ventilation rates below 0.3 air changes/hour.

As early as in the 1950's and 1960's individual scientists have emphasized the overriding dose contribution from radon (Rn) and its short-lived decay products (Rn-d) in comparison to those doses that the majority of their colleagues were dealing with at the time, i.e. resulting from the nuclear fuel cycle or nuclear weapon testing programmes (Hu 56, Po 65).

In the 1970's and the 1980's two series of scientific meetings stressed increasingly the importance of the radon issue, published in the form of proceedings of the US-DOE sponsored International Symposium Series "The Natural Radiation Environment", Houston (USA) and of the International Specialist Meetings held in Pocos de Caldas (Brazil), Bombay (India), Rome and Capri (Italy). During this period the first large scale national Rn surveys were conducted and regulatory guidelines issued in Scandanavia and Canada.

At the international level the Organization for Economic Cooperation and Development, Nuclear Energy Agency (OECD-NEA, Paris, France) and the Commission of the European Communities (CEC, Brussels, Belgium) reviewed all available Rn related information on metrology and dosimetry in the first half of the 1980's (OE 83, OE 85). Furthermore, CEC-NEA jointly initiated the International Intercomparison and Intercalibration Programme (IIIP), which has now been taken under the auspices of the IAEA. The CEC took a leading role in European research related to the Natural Radiation Environment (NRE) in general and in the Rn-issue in particular and supported several national programmes among its Member States (CE 80). In the second half of the 1980's the largest national Rn-research and survey programme so far has been undertaken in the USA (Co89) under the leadership of the Department of Energy (DOE) and the Environmental Protection Agency (EPA).

All internationally available information has been compiled regularly in the UNSCEAR reports. Over the past thirty years the previously seemingly invariable "constant" of 1 mSv for the average annual effective dose from all NRE sources was increased to 2.4 mSv (UN 88).

In view of the above 30+ years of evidence it is difficult to understand the statement made by the Health Physics Society in 1991, itself a most valuable source for radon-related data, ... "it was not until recently that it was realized that the largest radiation exposures received by most individuals come from the natural sources of radiation, primarily radon and its radioactive decay products " (HP91).

2. The global dimension of the radon problem

At all times everybody is exposed to radon (Rn) and its decay products (Rn-d) anywhere on earth. Therefore this topic warrants a global approach on the research and the regulatory level. In the following section some of the major international and national activities in response to the increasing significance of the Rn-problem are discussed.

2.1. IAEA-CEC coordinated research

In response to the requests from Member States of the International Atomic Energy Agency (IAEA, Vienna, Austria) and in recognition of the global concern over the Rn issue the IAEA, jointly with the CEC, initiated the Coordinated Research Programme (CRP) on "Radon in the Human Environment". The World Health Organization (WHO, Geneva, Switzerland) and the International Cancer Research Agency (IARC, Lyon, France) agreed to provide logistic support in all areas related to the assessment of potential health effects. The potential for US-EPA and US-DOE involvement in Quality Assurance Programmes and risk assessment studies of this CRP is currently being explored.

Altogether 111 projects from five continents have been recommended for a phase-wise inclusion in the CRP. In addition, 25 CEC-approved projects are part of the CRP.

The objective of the CRP is to coordinate international research efforts aimed at the quantification of the impact of environmental Rn on man. Four areas are emphasized:

a) international intercalibration and intercomparison of Rn-measurement technology;

b) standardization of large scale Rn-survey techniques;

c) institutionalised exchange of information on Rn-levels, dosimetric methods and associated risk assessment, and mitigation techniques through Research Coordination Meetings under the auspices of the IAEA;

d) establishment of an international databank on Rn. This databank would enable members of the international scientific community and national regulatory agencies to obtain structured access to the results obtained from the multiple large scale Rn-surveys, which will be performed over the next five years mainly in the USA, Canada, Africa, Europe and Asia, Provided that the input data have fulfilled certain criteria, these data sets can be used for follow-up research, ranging from optimisation of technical remedial measures to improved lung cancer risk assessment. Finally such a database facilitates the exchange of scientific and technical know-how from developed to developing countries.

The implementation of the first phase of the CRP started in 1990 by awarding 12 Research Contracts and 37 Research Agreements (Fig. 1). The second phase, concerning the acceptance of the remaining projects, is scheduled for 1992.

The CRP-Quality Assurance Programme (QAP) is an essential element of the CRP (Fig. 2). For this purpose it is intended to invite the participants in the former OECD-NEA/CEC International Intercalibration and Intercomparison Programme (IIIP), as they are: ARL (Melbourne, Australia), NRPB (Didcot, UK), EML (New York, USA) and US-BM (Denver, USA). These laboratories, well-renowned in Rn metrology, are able to act as "Reference Centres" for designated "Regional Coordinated Centres": Ministry of Public Health (Beijing, China P.R.) for the Asian-Pacific region; Institute of Radiation Protection and Dosimetry (Rio de Janerio, Brazil) for the South American region; Ghana Atomic Energy Commission (Legon, Ghana) for the African region; Institute of Atomic Physics (Sofia, Bulgaria) for the Eastern European region and Middle East; Centre of Radiation Hygiene (Prague, CSFR) for the remaining European regions.

Quality control is maintained by the interchange of Rn-detectors between Regional Coordination Centres and Reference Centres. This will involve an initial calibration and subsequent qualifying tests. The aim of the initial calibration is the establishment of calibration factors, lower limit of detection, reproducibility, accurance and linearity of the detectors used in the CRP. An exposure test regime in a Rn-chamber will include blanks, low-, medium- and high level Rn-exposure of the detectors, taking into account different climatic exposure conditions. The analysing laboratory will be informed of the actual exposure values. For the qualifying tests CRP-participants provide detectors to a Reference Centre as above, but the analysing laboratory is not informed of the exposure levels prior to the reporting of their results. This test will be repeated annually. Pre-defined criteria for passing the test will be used, e.g. the mean value for each group of exposure category would be within ± 25% of the calibration exposure (except blanks).

<u>Surveys</u> will be carried out in two stages. In a pilot Rn-survey all logistic and technical components for the follow-up large scale Rn-survey are tested. Secondary aims are the training of survey personnel and the establishment of the necessary national and regional programme infrastuctures. A follow-up large scale Rn-survey is aimed at determining yearly averaged indoor Rn-values using a standardized survey protocol. Since these surveys are carried out in areas with largely different climatic and socio-economic characteristics, it is necessary for the standardized format to be adopted to the local needs.

Each participant who does not already have an established integrating Rn-detection system, is provided with:

- passive open-faced track-etch detectors (material: LR 115) for short-term integrating screening measurements (exposure period: 1 week);

- passive electric-based ion chambers (material: permanently charged Teflon material) and/or passive track-etch detectors (material: CR-39) for repeated long-term integrating measurements (exposure period: 6 months).

In the pilot-type surveys, sites are selected on a pseudo-random method, based on population distributions, in one urban and one rural community each. Detectors are distributed and collected after exposure either by mail or survey teams, following the guidelines of a standardized experimental protocol. The large scale-type surveys are population-based, with statistically chosen sampling of dwellings within each

Member State. The detailed sampling method is country-specific and takes into consideration different approaches to approximate optimal randomization. The preferred method consists of a questionnaire being mailed to randomly selected individuals, together with a pre-paid, pre-addressed envelope. Upon return of the completed questionnaires, detectors are sent to those interested parties. This approach should improve the rate of active participation and maximize detector return. Optionally, the questionnaire can be completed individually by the survey team at the time of distribution of the detector in the randomly selected dwelling.

The results of the CRP are planned to be summarized in 1995 in the form of joint IAEA/CEC publications in the IAEA Safety Series and will include a summary of: a) the practical implications of the findings of the CRP, with the emphasis on international guidance on Rn control; and, b) the results of the IIIP on Quality Control organized prior to and under this CRP.

2.2. International research activities

The international research community is currently carrying out intensive Rn-ralated research. The main activities involve about 30 European research teams collaborating within the framework of the CEC Rn-programme (Si 91), approximately 50 US-institutions engaged in Federal Rn activities in the USA and worldwide additionally approximately 100 laboratories among the other IAEA-Member States. In this section some of the main Rn-related research activities outside the USA are described (the corresponding contact persons are listed in the Appendix).

a) Research in detection and analytical methods

Development of a device for continuous Rn-measurements in water, based on an integrated Rn-deemanation device and scintillation counter (A-Pi); the use of Po 210-activity on glass surfaces as an estimator for past Rn indoor exposure (A-Sa); optimisation of passive/open alpha track etch detectors for the short and long term estimation of the Potential Alpha Energy Concentration (PAEC), including thoron (Rn 220) daughters (A-An[1]); development of a low-level continuous Rn- and thoron- PAEC monitor, using α-spectroscopic analysis of Po 218, Po 214 and Po 212 (A-Ku); optimisation of a low level environmental thoron monitor, using Po 210-deposition on a surface barrier detector in a high tension field (A-Ke); thoron detection based on flow-through scintillation cells and multiple time analysis of recorded pulse events (A-Fa); simulation of rapidly changing environmental Rn/Rn-d levels with a walk-in type test facility (A-Sc); optimisation of quality assurance programmes for national indoor Rn-surveys (A-Bo); accuracy tests of integrating Rn-detectors (A-Me).

b) radon dynamics and aerosol science

behaviour of the unattached fraction in underground environments with variable aerosol concentration (A-Bu); the effect of mechanical air filtration and electrostatic precipitators on the unattached fraction and the equilibrium fraction of Rn-d indoors (A-Ko); sub-micron sized Rn-d particle size distributions in mines (A-Bol); modelling of atmospheric diffusion of Rn and thoron, describing the relationship between atmospheric concentration and the vertical diffusion coefficient (A-Cu); indoor behaviour of Rn-d in dependence of aerosol attachment, nuclide desorption from the aerosol and Rn-d plate-out on surfaces (A-Po); the effects of seasonal differences on indoor Rn (A-Pa); determination of the Rn and thoron exhalation rate and its dependence on surface cover and material temperature (A-Le, A-Al); development of rapid diagnostic techniques for determining Rn entry rates into dwellings (A-Ra); in situ-determination of Rn exhalation, combining time-dependent Rn and Rn-d measurements (A-Al); in situ-determination of gas permeability in soil with miniature probes (A-Da); temporal RaA-variability indoors, using continuous measurements (A-Ni); measurement of Rn-d equilibrium activity deposited on surfaces by analysis of the spatial distribution of alpha tracks on CR-39 (A-La); Rn diffusion characteristics through hydrocarbons for application in oil exploration (A-Ra[1]);

c) outdoor studies

airborne surveys in order to correlate outdoor-, indoor Rn levels and geology (A-Gr); ship-based atmospheric studies on the Rn- and Rn-d distribution trend over the equatorial Pacific Ocean (A-Mo); model validation describing the temporal variation and horizontal distribution of Rn in the atmosphere (A-Ik); wash-out effects on atmospheric Rn-d (A-Fu); temporal variation of the specific activity of Rn-d in rainwater (A-Yo); multi-parameter correlation of the Rn concentration with the variation of the atmospheric boundary layer (A-Ka); enhancement of outdoor Rn-levels due to uranium mining (A-Kr); optimisation of radon potential mapping, using airborne-, ground surveys and borehole radiometric procedures (A-Ba);

d) indoor studies

influence of fly-ash containing construction materials on indoor Rn levels (A-St); thoron and thoron decay products indoors due to building materials (A-Cl); survey of workplaces with elevated Rn levels (A-Di); Rn-levels in dwellings built on uranium deposits and phosphate rocks (A-Si); identification of dwellings with high Rn-levels due to wall constructions using soil (A-Do); atmospheric Rn concentration in underground subway transport systems (A-An); identification of sources in dwellings with extremely high Rn-levels situated in former uranium mining communities (A-Th); thoron decay product exposure assessment for inhabitants of volcanic tuff-made dwellings (A-Sc[1]); correlation of Rn-d levels with the unattached fraction in houses with anomalous Rn-levels (A-Ro); Rn-levels in tourist caves, show mines and historical monuments (A-Ro, A-Hu).

e) <u>dosimetry and risk assessment</u>

microdosimetry of inhaled Rn-d by simulating randomized energy deposition at different cells (A-Ho); low dose extrapolation of Rn-related dose-effect curves with a hypothetical threshold (A-Ci); lung cancer risk assessment based on case-control studies in normal and coal brick-dwellings (A-De, A-Wa).

3. <u>International regulatory approaches to radon control - a mosaic of options</u>

Over the past 25 years the International Commission on Radiological Protection (ICRP) has drastically changed its approach to Rn control. In 1966 the ICRP categorically declared that its dose limitations referred only to exposures from technical practices that added to the natural background radiation (IC 66). In 1991, however, the proposed revised recommendations acknowledge that "....radon in dwellings needs special attention" (IC 91). For existing dwellings the ICRP discriminates between the recommendation of a vague "guidance" for owner-occupied dwellings and an "action level" for rented properties, without specifying any numerical values. Also the advice provided on the choice of action level is rather philosophical, i.e. it should be such that the number of houses in need of remedial work should not be "unmanagable". From the view point of the ICRP a recommendation for a "new building" is not really warranted because the concentration of radon cannot be determined with confidence until its completion and having been occupied for about a year. By then it is an existing dwelling . Finally the ICRP admits it is proceeding "cautiously" and recommends to continue using its Recommendation no. 39, i.e. an equilibrium equivalent concentration (EEC) of 200 Bq/m3 as a "reference level" for new dwellings. This would result in an effective dose of 12 mSv/yr with the present lung model. However, "revised recommendations in due course" are already announced.

The World Health Organization (WHO) recognizes in 1989 that "...radon and its daughter products remain a matter of concern due to widespread occurrences and the total delivered dose" (WH 89). Using a different approach, it accounts for the extent of mitigation required in the case of existing buildings (Ah 90): if the annual average EEC exceeds 100 Bq/m^3, remedial actions should only be taken, provided they are simple to implement. This caveat does not apply if an annual average of EEC > 400 Bq/m3 is prevailant and then prompt actions should be taken. WHO recognizes "new buildings" as being a different situation than already existing dwellings and recommends that an annual average EEC of 100 Bq/m3 should not be exceeded.

The Commission of the European Communities (CEC) recommends to use a dose-related "reference level". If an effective dose of 20 mSv/y is exceeded, this should be "cause for consideration" of "simple, but effective" countermeasures (CE 90). Applying presently available dosimetry this corresponds to an annual average EEC of 200 Bq/m^3 (F = 0.5). Also the CEC recognizes the difference between existing and new buildings and recommends in the latter case a "design level" of 10 mSv/yr (= EEC: 100 Bq/m^3; F = 0.5). It is emphasized by the CEC that a) all decisions should be based on annual averages of Rn or Rn-d, using integrating techniques;
b) adequate Quality Assurance Programmes should be in effect.

In the following two examples for national regulatory actions are discussed. In Austria the total radiation exposure indoors resulting from building materials is regulated, i.e. the sum resulting from external gamma radiation and exhalation of Rn (ON 88). Different equations apply for single component- or multiple-compound building materials. The materials are considered suitable if the resulting effective dose from the total indoor exposure does not exceed the average national value of 2 mSv/yr. Contributions from cosmic rays, Rn from drinking water, etc. are excluded in this recommendation on building materials.

In 1980 the Swedish government took the lead worldwide to introduce a system of comprehensive limits and recommendations for decreasing Rn concentrations in all dwellings (NB 80). At present a Rn- "action level" of 200 Bq/m^3 is used for existing dwellings, provided simple measures can be taken; otherwise 800 Bq/m3 are recommended. For new dwellings a Rn- "design level" of 140 Bq/m3 is in effect. In 1985 Rn has been recognized officially as an urgent health problem requiring action (SG 85). Therefore, the government recommended each municipality to take appropriate measures to ensure via building permit that in new buildings the average collective exposure to Rn-d and to gamma radiation is decreased as far as it is practical and economically reasonable (Fa 90).

4. Recommendations for a unified approach

Radon represents a multidisciplinary issue on an international scale. Therefore it appears advantageous to use a unified approach to its solution. Such an internationally coordinated approach should address the following areas:

4.1 Research needs

In the following areas further research is needed in order either to overcome actual lack of data or to improve existing databases.

a) Source Term Characterisation:

Radon 220 (Thoron, Tn) and its decay products (particularly ThB) may represent a non-negligible component of the indoor environment in some areas; more measurements are needed to characterize occurrence and dynamics of these nuclides; Rn-related convective/advective/diffusive/ transport phenomena need quantification for a variety of environmental boundary conditions, such as under the influence of meteorological parameters; interaction of pressure-driven flow with sûbsoil; multizone transport and interzone flow; quantification of Rn-entry into spaces; Rn/Tn generation and mobility in soil and rocks as a function of: soil moisture, -porosity, -type, -depth, weathering; emanation process into gas and vapour phases dependent on pore space, grain size, permeability; microdistribution of radium 226 within grains.

b) Aerosol Sciences:

Chemical and physical characteristics of Rn/Tn and their decay products, e.g.: formation of cluster ions and their reaction products; dynamics of Rn-d/Tn-d interactions with indoor aerosol (size distribution, diffusion coefficient, recoil phenomena, plateout rate); Rn-d/Tn-d interaction with other indoor pollutants: generation rate of free radicals, ions, neutral products; long-term measurements of unattached fraction in a variety of environments, including size distribution studies and humidity effects.

c) Dosimetry:

Microdosimetric calculations to obtain values for the quality factor and RBE for Rn-d; biological dosimetry for evaluating prior Rn-d/Tn-d-exposure, using samples of bone, teeth, blood, hair, etc; refined dosimetric modelling for infants, children, sick and older people using actual morphological and physiological data rather than scaling factors only; development of species-specific physical models of different regions in the respiratory tract.

d) Radiobiology

Molecular approach to mechanisms of Rn/Tn-induced injury:
Rn/Tn-in vitro exposure of human cell cultures; biophysical and biochemical modelling for the identification of cellular markers for pre-malignant or malignant cells; use of molecular probes of genes cloned as recombinant DMA molecules to study Rn/Tn-induced DNA changes; activation of oncogenes;

Cellular approach:

quantification of the changes of parameters indicative for transformation processes, such as:
anchorage-independent growth, immortalization, growth enhancement; abnormal expression of growth factors; adaption studies to ultra-low levels of Rn-d exposure (hormesis); Tn-d distribution in different organs after inhalation; interaction of Rn-d/Tn-d smoke and other irritants known to occur indoors and underground;

4.2 Logistic requirements and aspects of programme design

Over the next few years a large number of Rn-programmes will be carried out worldwide. In order to achieve optimal cost-effectiveness and comparability of results international coordination is desirable also in the implementation of these programmes, addressing logistic requirements and programme design:

a) standardisation of the data collection-methods for describing the Rn exposure indoors and outdoors in different types of exposure situations (homes, schools, offices, factories, public buildings, recreational areas, health spas, mines) and reflecting the subsequent use of the data (real estate transaction, design of mitigation procedures, epidemiological research);

b) definition of minimum criteria to be fulfilled by quality assurance programmes concerning different measurement programmes (short-term integration, long-term integration; measurements of Rn-, Rn-d, thoron daughters and unattached fraction; Rn determination methods for soil gas, water, exhalation rates);

c) establishment of an international Rn-databank

d) harmonization of the international <u>regulatory approach</u> to risk limitation from Rn-exposure, differentiating between the residential-use of owner occupied buildings, rented accomodations, public buildings and work places;

e) provision of <u>information material</u> (graphical, audio-visual) for specific target groups, such as public health services, scientific-technical community, real estate agents, Rn-testing companies and contractors, and the media. This material should be scientifically sound, presented but also sufficiently interesting to reach the target audience. It should assist in obtaining a positive response from the public, thereby adding to improved control of the exposure situation.

f) development of durable <u>Rn-mitigation techniques</u> for different architectural styles and geo-climatic regions, taking into account the cost-effectiveness of achievable dose-reductions;

Summarizing it appears advantageous to find an international agreement on a unified approach to view the issues of "Radon in indoor air" and related public health risks from individual and collective exposures in a consistent manner with risks from other radiation sources but also from all other contaminants occurring indoors, such as microorganisms, organics, combustion products and passive cigarette smoke.

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Appendix

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Fig. 1: Participants in the IAEA Co-ordinated Research Programme "Radon in the Human Environment" (Status: February 1991)

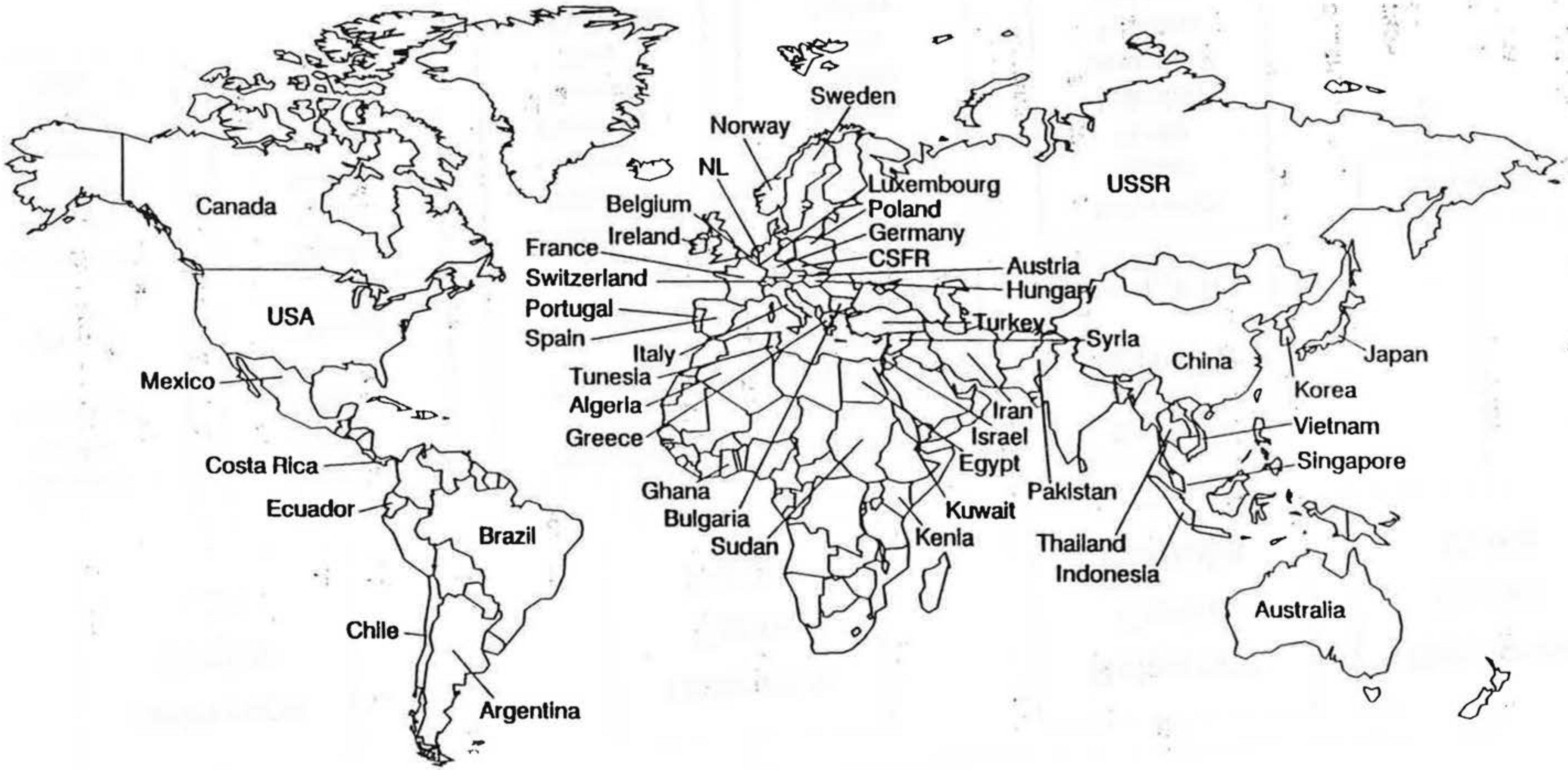

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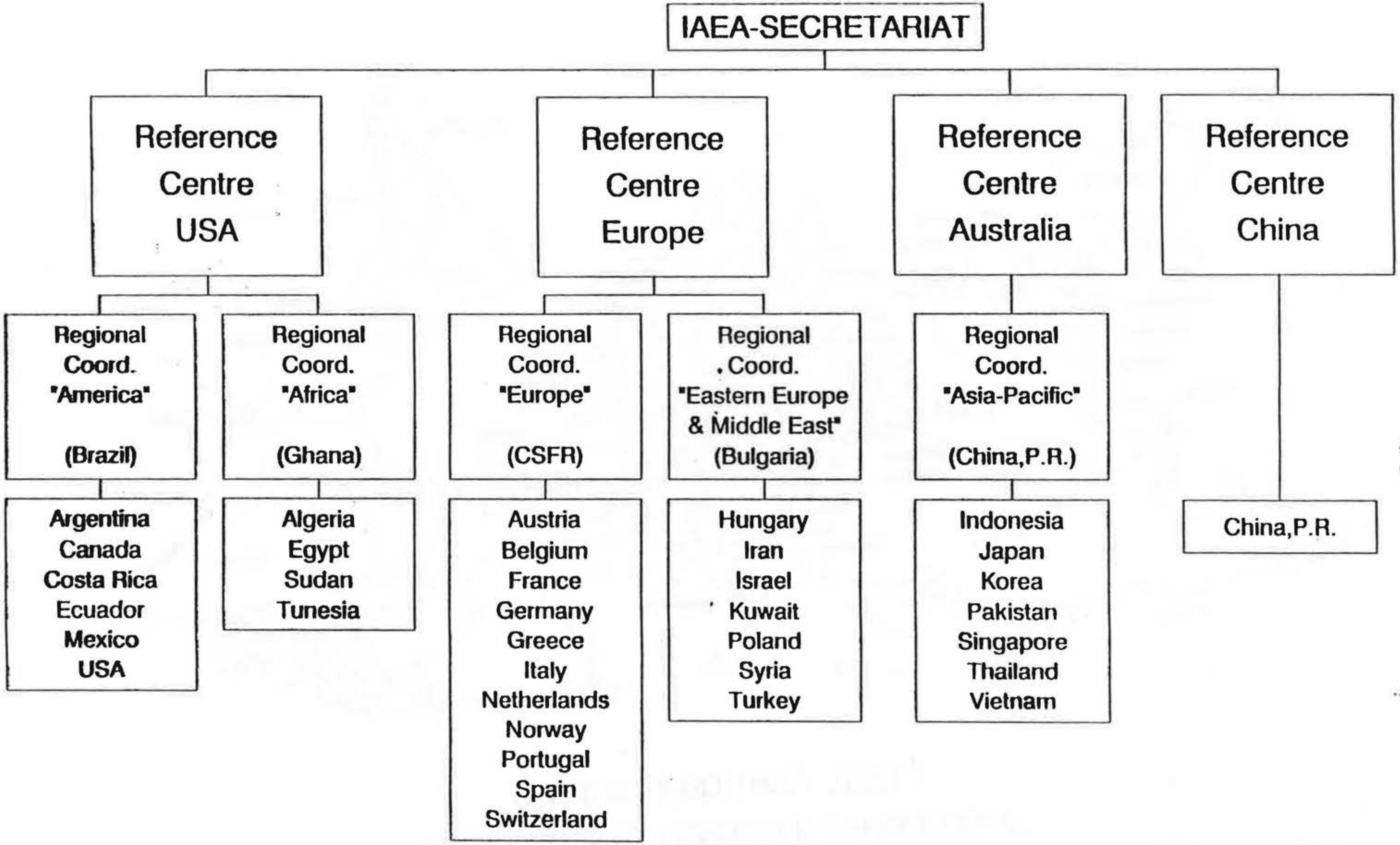
Fig. 2: Implementation of Quality Assurance Programme within the Framework of the IAEA-CRP "Radon in the Human Environment"



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