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environment and quality of life

Mobilization of heavy metals from fossil-fuelled power plants, potential ecological and biochemical implications

II — Definition of the problem using a critical path approach, motivation, objectives and research programme to study the European situation

EUR 6998 EN
Part II

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ABBREVIATIONS

HM : Heavy Metals

FFPP : Fossil - Fuelled Power Plants

PREFACE

The pressing need to produce more electrical energy by fossil fuelled power plants with a greater use of coal may result in increased mobilization of heavy metals at fossil fuelled power plants with increased contamination hazard of man and environment.

Because of the complexity of the possible interactions between heavy metals with environment as well as man, the nature of the risks that the toxic metals mobilize at fossil fuelled power stations represents is problematic and involves multidisciplinary efforts to establish dose-effect relationships which could serve as a basis in determining maximum permissible release rate for the environment and maximum permissible doses for man.

Research reports of the JRC on this subject have been divided into a series of five reports with the purpose of examining and evaluating critically the available data giving a list of topics which may serve as a guid-line for a research project which should be undertaken to study the EC situation. They are:

Mobilization of heavy metals from fossil-fuelled power plants, potential ecological and biochemical implications

- I Electricty demand, installed capacity and geographical location of the fossil-fuelled power stations in the territory of the European Community;
- II Definition of the problem using a critical path approach, motivation, objectives and research programme to study the European situation;
- III Heavy metal content in coals burnt in the European power plants;
- IV Assessment studies of the European situation;
- V Natural radionuclides in coals and coal ashes from European conventional power stations and evaluation of a potential environmental impact.

This work is the second of the series and provides technical basis for a guidance as to how the problem of HM from the European FFPPs might profitably be approached underlining the areas of needed experimental research.

1. General considerations

The perspective for estimating the biohazard due to the mobilization of H.M.s from FPPP requires much conceptual effort in order to assess clearly the complex problem on a scientific basis.
The policy of the programme of action of the EC on the environment is directed to improve the setting and quality of life in order to prevent, reduce as far as possible, eliminate pollution including HM pollution as well as to maintain a satisfactory balance ensuring the protection of the biosphere. Although the setting of exposure limits and legal environmental quality standards for HM from FFPP such as maximum permissible release rate and maximum permissible concentration in critical material is a matter of policy decision, the determination of criteria is essentially a scientific tas which requires integrated critical approach. The development of these standards involves the definition of HM protection standards for organisms (dose - response relationships), which are applied in the critical path approach for a real environmental situation created by the activities at the FFPP area.
This chapter defines the critical path approach for a scientific evaluation of the environmental and human health impacts of HM as a result of their mobilization from FFPP during energy production.

2. The critical path approach

Critical path analysis applied to the study of environmental and health impact of HM is based on the identification of both of their most important pathways between all the possible (the control of which permits a reasonable control of all other pathways) and of the critical materials which are submitted to their greatest degree of exposure. The determination of the limiting environmental capacity, the rate of release of HM from PP which at equilibrium will result in a rate of exposure of the target per unit time equal to that defined by the primary protection standard, is the fundamental parameter to be determined. Unfortunately, some important factors contribute to make its determination very difficult:

- further complication of the problem by numerous variables for establishing relationships between HM exposure and biological effects such as populations of different susceptibility, the simultaneous interaction with other pollutants, the evaluation of the normal geological background, the evaluation of the relative contribute of other HM sources;
- the virtual absence at present of well defined protection standards for heavy metals which must be used in the critical approach giving the possibility to the regulatory authorities to set rates of release below those compatible with life.

Figure 1 summarizes the requirements for the critical path analysis to obtain a full assessment of the impact of HM mobilized from FFPP on the environmental quality and human health.

The following considerations can be made:

- The first part of the critical path approach should generate positive data for applying models which study the evolution of HM in the biosphere.
- Any ecotoxicological evaluation as well as the evaluation of the possible impact on human health requires the use of protection standards (dose-response relationships). It is helpful to recall the need to consider the physiological and toxicological effects of metals as a continuum in a wide range dose-response curve. Potentially, every element has a biological function that can be assessed only against a background of a deficient state. Concentrations of metal higher than those required to maintain essential functions, may have secondary effects. At still higher concentrations, every element is potentially toxic, eventually lethal (Fig. 2). The finding of the exposure-effects curve represents the basis for any evaluation of acceptable levels of trace metals exposure.

From these considerations we can draw now the problem of HM from fossil fuelled power plants and their potential impact on the environment and human heath should be studied as well as the experimental activity need. Two steps must be considered:

a) definition of the magnitude of the problem, evaluating if the amounts of HM mobilized can really interfere with the natural fluxes of HM in the environment and what is the interference factor in respect to other sources of HM which can pollute the environment such as from industrial activities. This step requires the contribution of experimental in-plant measurements and laboratory simulation experiments as well as the development of analytical model calculations;

b) development of protection standards in order to establish where we are on the dose-response curve. This step requires both monitoring efforts (in field measurements) on surroundings power plants, on humans (epidemiological investigations) and on the environment (analysis of soils, water, sediments, vegetation and air) as well as biochemical and toxicological studies on biotic and laboratory animals.

Taking into account the above considerations, an analysis of the single sequential steps of the critical path approach applied to the problem of HM from FFPP is possible (Fig. 3).

2.1. The fate of HM at a FFPP

Preliminary conceptual considerations on the possible pathways of HM at a FFPP are needed prerequisite for applying the critical path approach. The pathways can be drawn from a detailed analysis of a flow sheet concerning typical activities at a FFPP. The determination of the movements of HM at the FFPP are the basis to understand their environmental behaviour after release (Fig. 4).
It appears that HM can enter the environment through some main processes generating gaseous, liquid and solid wastes:

- run off of the stored coal;
- emission into the atmosphere from the chimney;
- emission via waste waters originated by internal operating process at the plant;
- treatment and disposal of ash as a result of the retention of HM in the particulate ash which is trapped by electrostatic precipitator (fly ash) or deposited at the bottom of the boiler (bottom slag).

The first three situations release HM in the environment surrounding the initial source and in a second time HM can be transported far from PP via plume or water.
The third situation can release HM into the aquatic environment near to the power station which can be transported far from the initial source and generates also a solid waste disposal problem which makes the impact of HM with different parts of the ecosystems far from the plant area possible, depending on the use of the waste ash.
A fundamental difficulty of such study is to decide how much the formulation of the dispersion model must be detailed. This involves the question on how many physical and biological compartments should be considered. For example, the HM transport in water could consider water, sediment, suspended material, plankton, aquatic plants and fishes originating a complex model. A further separation of living material (bacteria and invertebrates) should bring this to a more complicated level (Fig. 5).
In this section we consider a conceptual model at a level sufficiently detailed to d escribe all pertinent factors being at the same time simple and flexible to permit an analysis of the main parameters on the basis of existing data. In particular, attention is paid to a modeling approach for quantifying environmental impacts of HM released from operational processes at a power plant considering primary as well as main secondary possible environmental pathways.

2.2. Analysis of the various HM pathways and transport

The purpose of this section is to evaluate the possible pathways of HM released from FFPPs to the environment.

2.2.1. Emission into atmosphere.

HM emission into the atmosphere from the stack represents a rapid mode of transport moving away them at large distance with the possibility of contamination of large area. HM so released enters directly into the environment and has a potential direct or secondary impact on all the various parts of the ecosystems including man. The main pathways for humans and animals is direct inhalation. The pathways to biota are via direct deposition in freshwater. Plants and soils can be contaminated by direct foliar and soil surface deposition. Food and water, soil run off and root uptake of HM deposited on soil surfaces represent possible potential routes of HM impact on humans and animals, biota and plants respectively.

2.2.2. Ash pond water discharge.

Fly ash from the electrostatic precipitators and bottom ash from the furnace can release trace amounts of HM into waters when transported by water from the precipitator or from the furnace bottom to the settling pond. The ash pond effluent waters from the decant channel are discharged into rivers. The pathways for biota is a direct exposure. The seepage through the soil, with consequent penetration of the surface aquifer and groundwater contamination should be considered. Secondary pathways could be aquatic plants and sediments as well as animals and humans via food chain.

2.2.3. Other wastewater discharges.

They include HM into waters from periodic boiler-tube cleaning, from lime or limestone scrubber system for flue gas desulfurization, fire side and air-preheater cleaning as well as cooling tower blowdown. The pathways are similar to those reported for the bottom ash and fly ash transport.

2.2.4. Coal pile run-off.

Toxic metals may be released from coal pile basin when moisture comes into contact with stockpiled coal because the leachate produced is a highly acidic wastewater. Coal pile run off results from rainfall that percolates through coal storage pile. The major potential HM pollution associated with coal drainage is the contamination of the hydrosphere as well as soil. The entering of the dissolved HM into the local groundwater by seepage is also a pathway which should receive attention.

2.2.5. Disposal of fly ash and bottom ash.

Ash disposal may pose significant environmental problems because it represents a potential for contamination of soils, surface water and groundwater by the wind and water erosion everywhere where heavy ash and fly ash are deposited or utilized in construction projects.

From these considerations we can distinguish two types of possible environmental impacts:

- local direct impact surrounding PP area on soil, waters, plants, animals and man via air;
- secondary indirect impact far from the PP area due both to long range transportation of HM via plum or water and transportation of the disposal solid waste to another area. These secondary pathways should include food chain transport.

2.3. Quantity and characteristic of heavy metal mobilized

For any quali- and quantitative evaluation of the possible environmental and health effects impact of HM from FFPP, the knowledge of their concentration in the different environmental recipeint media as well as their characterization is needed. This implies the measurement of HM:

- released during the combustion process from the stack;
- in the solid ash disposal;
- in wastewaters discharged directly from the plants as well as from the ash pond;
- in coal-pile run-off ;
- in fly ash run-off.

The determinations concerning the first two points involve mass balance studies through the power station by in plant sampling including the determination of HM in different coal types burned as well as in fly ash, bottom slag and atmospheric emission.
The detailed characterization includes the determination of HM in fly ash as chemical form as well as a function of particle size which can affect the bioavailability of the different elements.
The other three situations involve the analysis of HM in different wastewaters as well as in the different parts of the ecosystems, such as sediments, soils, vegetables, biota.

2.4. Dispersal characterization

In order to establish relationships between the release of HM from power plant process and concentration in the recipeint media, the knowledge of some baseline data, such as the actual levels of HM present in the environment as well as the mode of dispersal of HM released from the plants must be known. The dispersal characteristics of HM immitted in the recipeint medium is normally be done by the use of dispersion models.

2.4.1. Atmospheric dispersion.

Atmospheric models permit calculations of the HM concentration in air as well as their diffusion and deposition rates at various distances and directions surrounding the power plant. Numerous baseline data are needed including:

- characterization of HM emission coupled with chemical and physical state and knowledge of the emission rate;
- dispersion parameters, emission height, deposition and transformation rate, washout coefficient;
- topographical, meteorological and climatic data.

2.4.2. Hydrological dispersion.

Hydrological models must be applied to predict HM dispersion in the hydrosphere on the basis of the change in water quantity and purity consumed at power plants.

2.4.3. Terrestral dispersion.

Terrestral models permit to predict the movement and the concentration of HM in the terrestral ecosystems, such as soil movement, plant uptake and retention as well as the decomposition rates and movement from litter to soil.

2.5. Bioenvironmental effects

The problem of evaluating and forecasting environmental consequences due to the mobilization of HM from FFPPs is very complex because, in addition to the extensive and different effects on living and non-living environmental components, long-lasting or irreversible effects may appear after a long latency period.

The environmental effects of HM from fossil fuel burning plants can occur at all the environmental levels as shown in the model of Fig. 4. They include:

- atmospheric effects, such as an increased concentration in the atmosphere and deposition on soil, water and biotic surfaces which can impact air, land, water, vegetables, animals and man;
- hydrospheric effects, such as an increased concentration of toxic metals in water systems due to the deposition of atmospheric HM emitted from the streams, soil run off of the ground-deposited power station steak emission as well as to the leaching of HM from fly ash in the effluents from ash setting basin. A potential impact with river, lake, seawater and drinking water after seepage to the ground-water is possible;
- soil effects, due to either wet or dry deposition of HM associated both to the emitted particulate from the stack and to the release from disposal fly ash. A potential possibility of low equilibration between the chemical form with which

certain HM enter soils could after the normal plant bioavailability for these metals.

- effects on vegetation, such as an increased level of HM on the plant compartments due to aerial deposition on external surfaces, uptake of externally deposited materials by leaf and stem surfaces, root uptake and translocation. The problem of the phytotoxicity is further complicated from the differential species sensitivity;
- effects on biota, which can occur at the individual and population levels altering life cycle behaviour and reproductivity, population size and biomass with the possibility to induce genetic damage. The quality and magnitude of direct effects on biota will vary among species and an higher toxonomic group complicating further this problem.

For a complete assessment, the extent of these effects must be predicted. The use of ecological effects models in addition to the transport and dispersion models is needed. They require data such as on the effects of HM on reproduction, competitive behaviour, mortality and morbidity. The models should include regional data for the communities at the site of location of the power plants.

These studies, directed to establish both a daily intake of HM in the different ecological compartments and a daily exposure of biota, involve laboratory and in field research such as:

- analytical activity for monitoring HM in the various parts of the ecosystem surroundings, coal fired steam plants collecting air, soil, vegetables, waters, sediments and biota. These in-field campaigns should provide continuous input of environmental baseline data for continual model validation and implementation;
- biological investigations in order to establish now biogeochemical processes might affect the long term behaviour of HM with the determination of their biological and chemical distribution and transformations in the different ecological compartments, the interaction with other physical, chemical or biological factors as well as bioaccumulation.

2.6. Human health effects

The potential effects of HM from FFPP on human health could occur directly by inhalation and oral ingestion via drinking water and food, as well as indirectly through food chain processes. The problem of estimating health effects in man is very complex because relationships between the exposure and specific pathological process in power plant areas is hindered by many variables such as different susceptibility of populations, the synergistic and antagonistic effects, the presence of many environmental factors,

the normal geological background and the need to evaluate the effects of subacute doses over a long time (long term - low level exposure (LLE) conditions).
Neither biological monitoring for toxicological and epidemiological investigations nor tissue banks of autopsy material in areas around FFPPs by themselves are sufficient to evaluate the environmental health aspects of HM pollution caused by fossil fuel combustion.
Although this subject will be extensively examined in the third report of this series, which will include biochemical, toxicological and epidemiological considerations, we underline here that the contribution of all possible routes of entry to man to the total daily intake of HM is a fundamental parameter that must be known. These contributions should be calculated using human dose models for total dose prediction including those from food chain processes which require data on source, pathways, diet and local data habits taking into account also socio-economic factors.

2.7. The global assessment of exposure to HM

In order to reach the final objective for a full assessment, that is, the setting of emission standards establishing the maximum permissible release rate of HM in the environment and acceptable maximum intake in man, the combined results of laboratory experiments, in-plant and in-field monitoring activities and predictive model calculations must be evaluated in relation to environmental quality standards and protection standards for man. Since the availability of these standards is a fundamental requisite to set emission standards, research on dose-response relationships where information is inadequate must be carried out in parallel to the in-plant and in-field chemical and biological monitoring activities.
Fig. 6 shows schematically the outline of the research as well as of the steps for the setting of emission standards related to the mobilization of HM from FFPPs.
The preparation of reviews covering all the information available from published scientific reports relevant to the establishment of the relationships between the exposure to HM from FFPPs and its effects on man's health represent the scientific basis for the further policy decisions concerning the setting of exposure limits.
Since it is impossible to demonstrate experimentally a no-effect level which makes impossible to determine threshold limits for a population group as calculated mathematically, a risk/benefit analysis should be done before permissible exposure rates are established. The comparison between anthropogenic flux of HM to the different compartments of the ecosystems from fossil fuel burning with those of industrial emissions or other sources and the natural fluxes might originate an interfering factor which could be very useful for this scope.

2.8. Primary protection standards

The use of protection standards is an essential requisite to evaluate the significance of the results derived from the various steps of the critical path analysis applied at the problem concerning the mobilization of HM from FFPPs. Since the application of basic standards based on arbitrary concepts may lead to a totally unrealistic and misleading proposal in relation to target exposure, the setting of emission standards for HM mobilized from coal burning power stations must be guided by primary protection standards developed on rigorous scientific basis.

At present, the World Health Organization (WHO) in collaboration with many organizations of the United Nations, with other inter-governmental organizations such as OECD (Organization for Economic Cooperation and Development), CMEA (Council for Mutual Economic Assistance, CEC (Commission of the European Communities) and non-governmental organizations such as IAOM (International Association of Occupational Medicine), ICSU (International Council of Scientific Unions), ICRP (International Commission of Radiological Protection) and others, is giving considerable effort to setting primary protection standards for HM.

Table 1 reports elements which received priority in the WHO environmental health criteria pluriannual programme.

At present, much experimental work is needed, however, to set these standards, a fundamental tool for any scientific regulation of the introduction of HM into environment from different sources. It is helpful to recall the information that, as a rule, is needed to set protection standards for HM because they suggest the type of research that must be carried out:

- chemical and physical properties;
- sources of environmental pollution;
- environmental exposure levels (in air, water, food, in the working environment and other conditions of exposure);
- environmental distribution, transport, transformation and bioconcentration;
- metabolic pathways and biological effects;
- experimental toxicity studies (including synergism and antagonism);
- epidemiological and case (clinical) studies;
- estimation of the total human exposure from all sources;
- exposure-effect and exposure-response relationships;
- maximum permissible levels (as established in different countries for various environmental media, including occupational exposure);
- guidelines for primary protection standards

TABLE 1 - Priority given in the WHO environmental health criteria pluriannual programme concerning heavy metals

Priority	Preparation of nex criteria documents	Review, extension and evaluation of existing WHO documents	Review and assessment of national criteria documents by WHO as they became available	Preliminary export assessment and further research
A	Mn	Cd, Pb, Hg	As, Be, Cr, Cu, Ni, Se, V, Zn	Sb, Bi, Co, Li, Pd, Pt, Sn
B				Ba, Ge, La, Mo, Ti, Te
C				Al, Ga, In, Fe

DETERMINATION OF THE POSSIBLE CRITICAL PATHWAY OF HM AS A CONSEQUENCE OF THE FOSSIL FUEL ENERGY GENERATION

↓

IDENTIFICATION OF TYPES AND RATES OF HM MOBILIZATION IN THE DIFFERENT ENVIRONMENTAL COMPARTMENTS

↓

DETERMINATION OF HOW HM ARE DISPERSED AND TRANSFERRED TO VARIOUS RECEPTORS IN THE ENVIRONMENT (HUMANS, ANIMALS, PLANTS, MATERIALS)

↓ ↓

CHARACTERIZATION OF THE RESULTING ENVIRONMENTAL IMPACT	CHARACTERIZATION OF THE RESULTING HUMAN HEALTH IMPACT
↓	↓

GLOBAL ASSESSMENT OF EXPOSURE

Fig. 1 : The critical path approach for the full assessment of the mobilization of HM from FFPPs and their potential ecological and biochemical implications to provide a stronger scientific basis for environmental policy decisions.

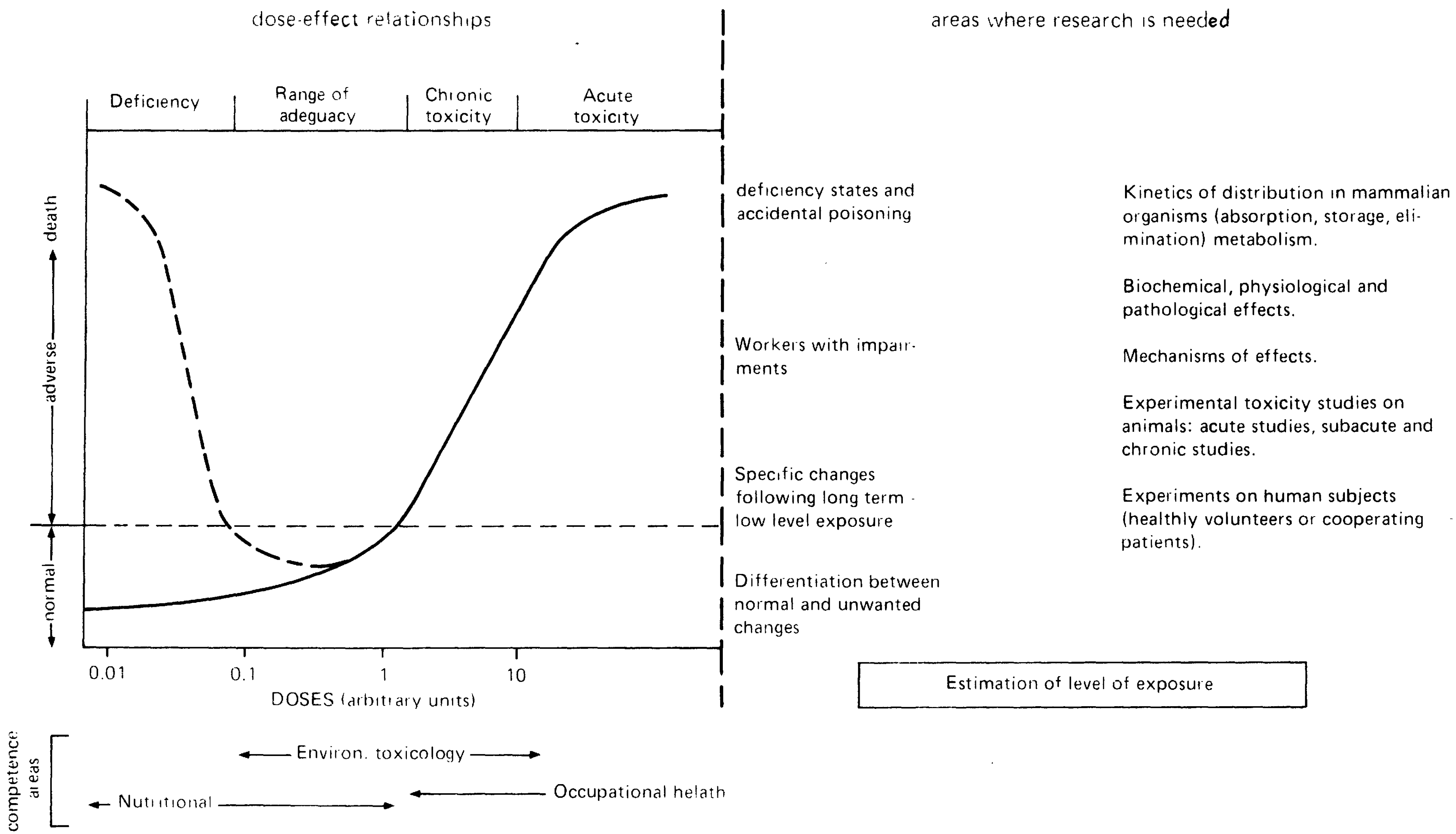

Fig. 2 – **Significant activities to establish relationships between exposure to heavy metals and the effects due to the exposure**

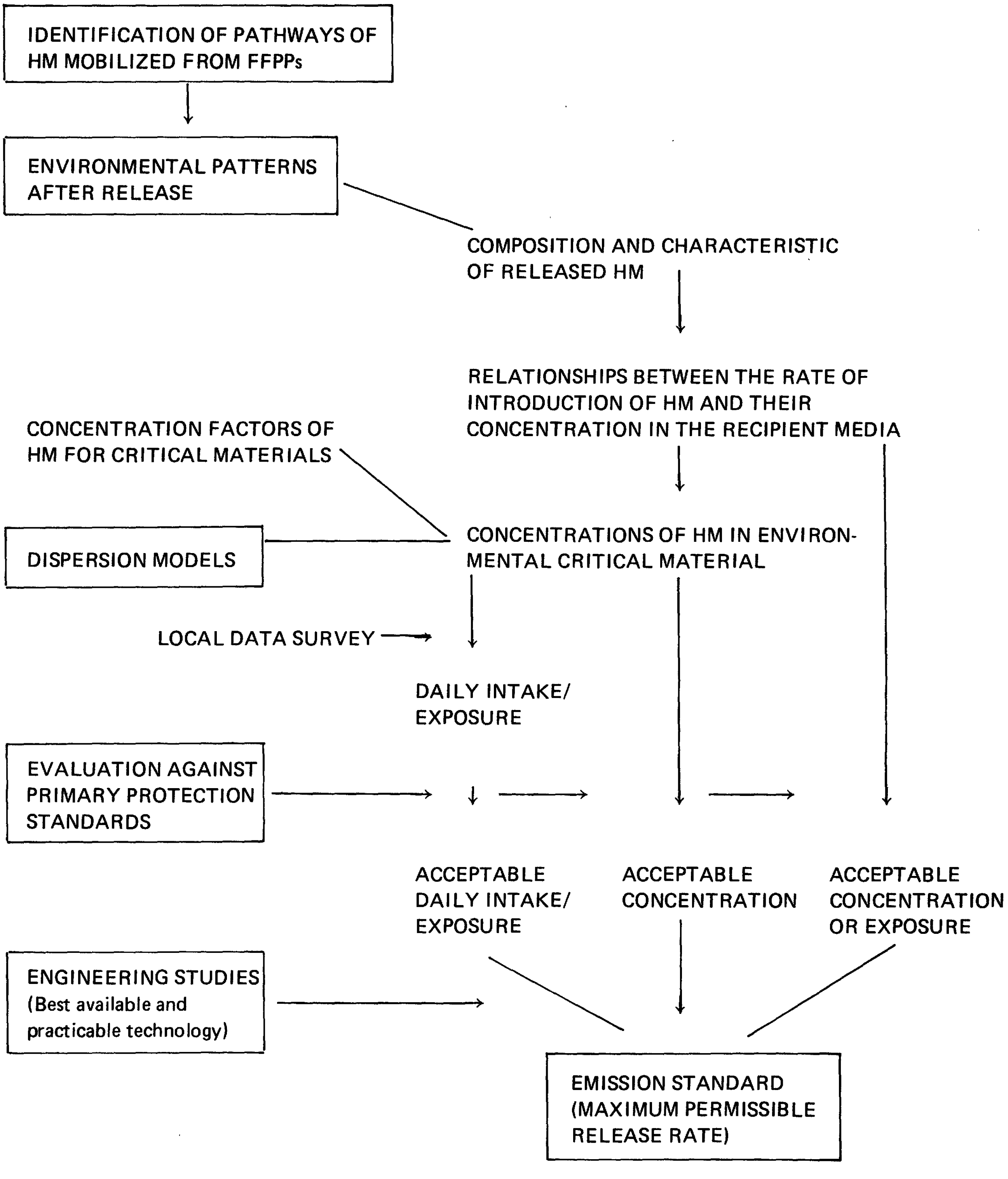

Fig. 3 : The critical path approach used to study the potential environmental and human health impact of HM mobilized from FFPPs situated in the territory of the European Communities.

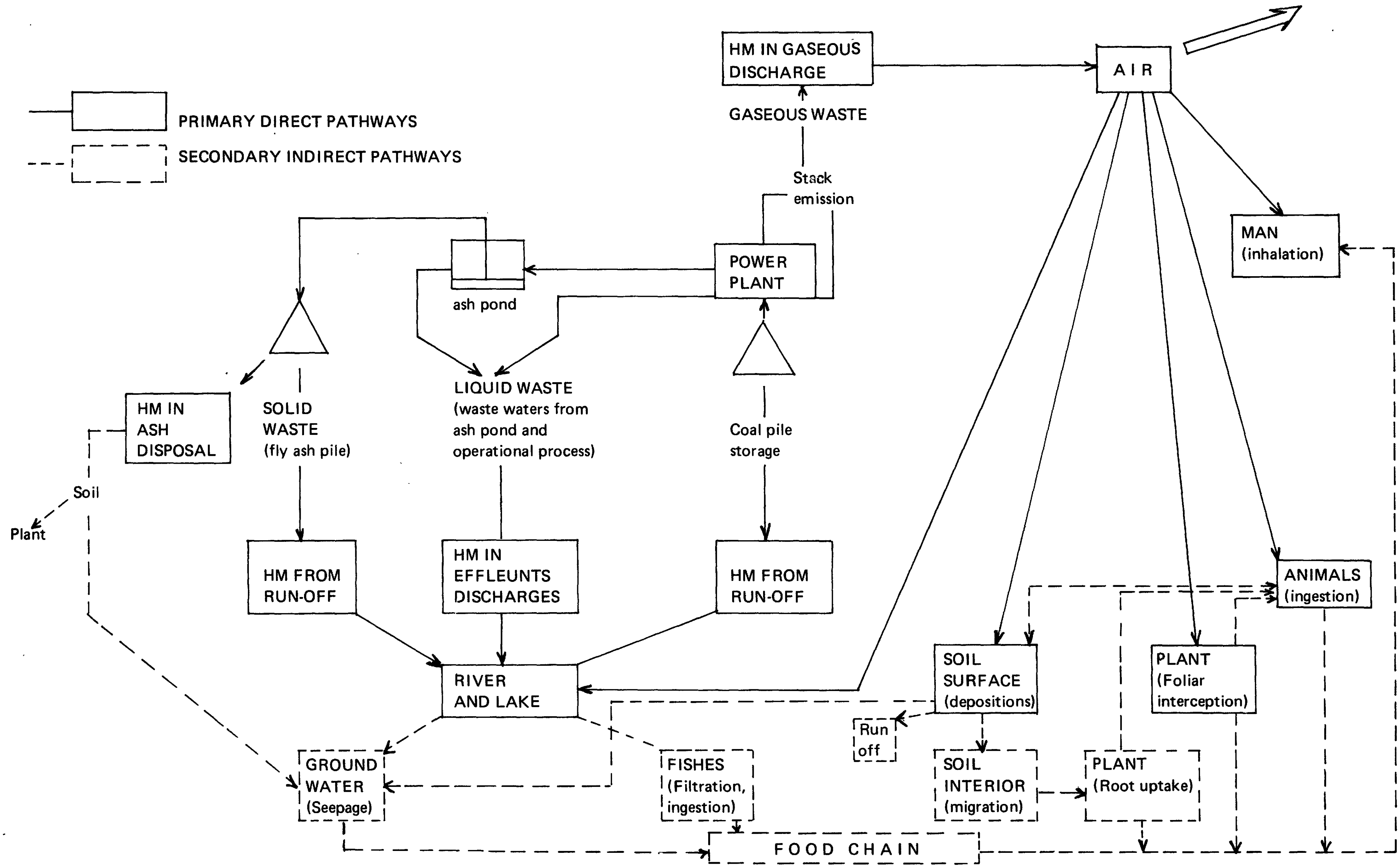

Fig. 4 : Possible environmental pathways and transport of HM mobilized in the area of an operating coal-fired power plant.

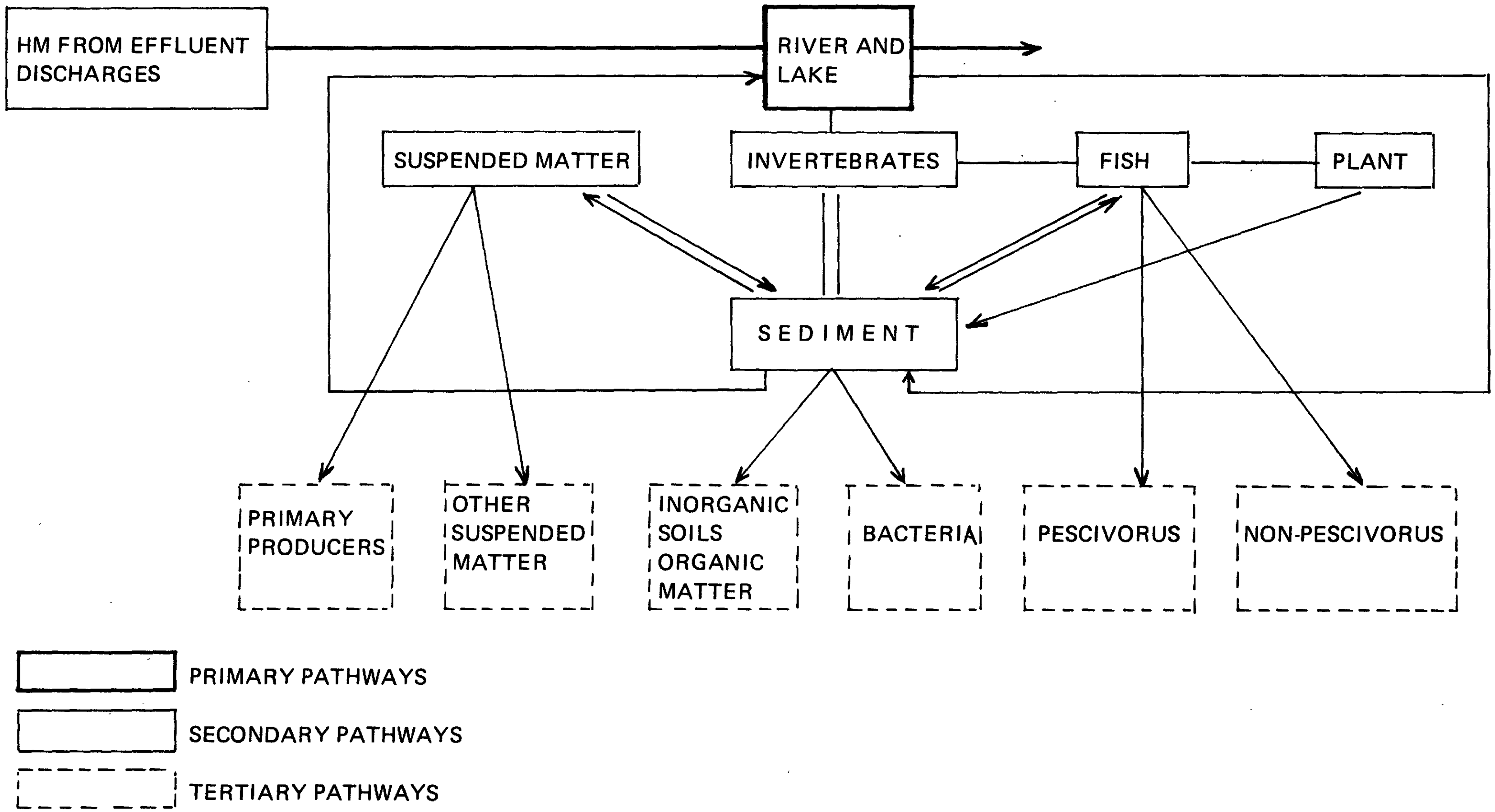

Fig. 5 : Environmental submodel to study the pathways and transport of HM in effluents discharged in river or lake as a consequence of the activities in a power plant area. The figure shows as the model can be subdivided more and on complex levels.

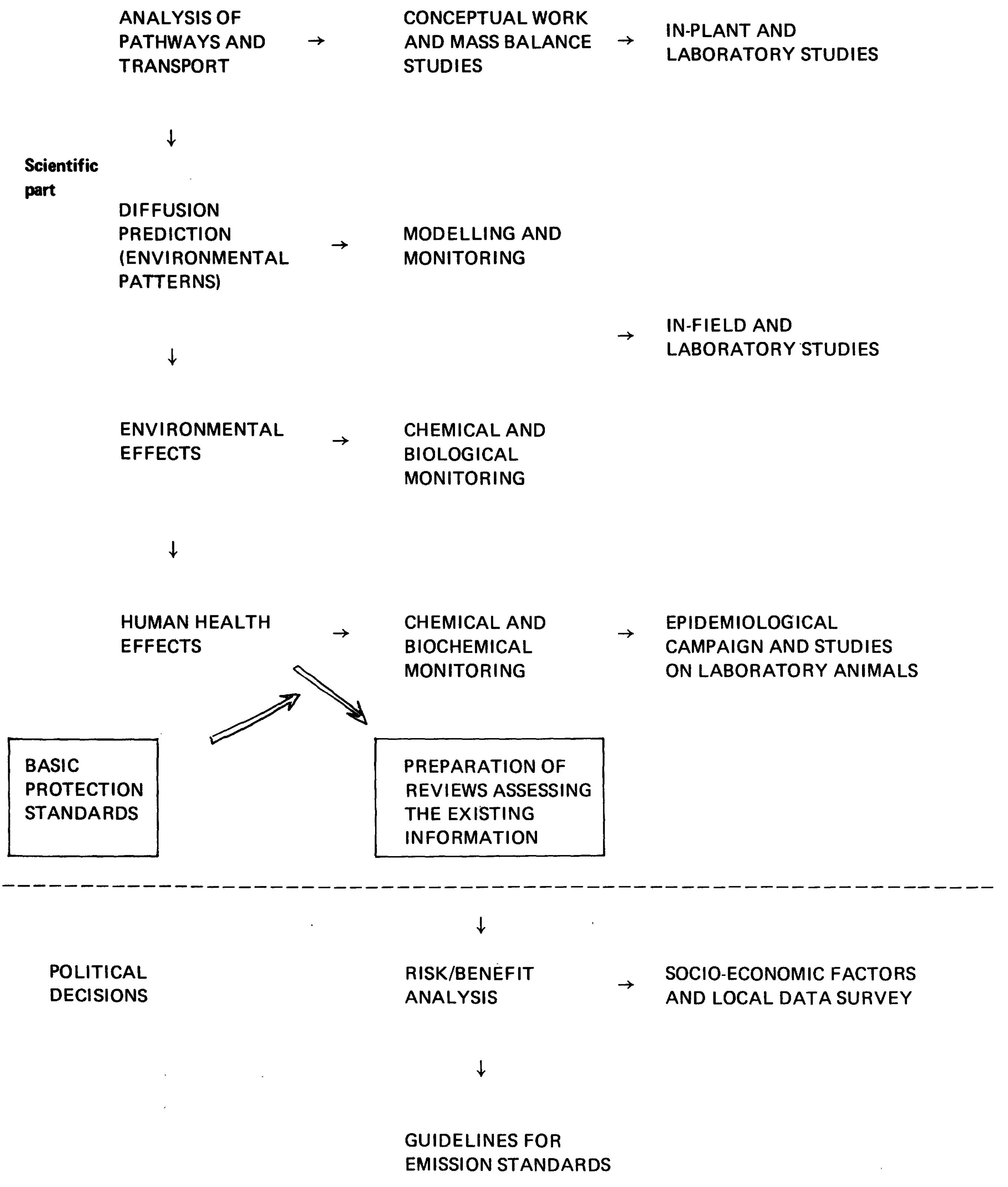

Fig. 6 : Generalized flow diagram for an assessment study on the mobilization of heavy metals from FFPPs and their potential ecological and biochemical implications.

European Communities — Commission

EUR 6998 — Mobilization of heavy metals from fossil-fuelled power plants, potential ecological and biochemical implications

II — Definition of the problem using a critical path approach, motivation, objectives and research programme to study the European situation

By L. Goetz and E. Sabbioni

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II — Definition of the problem using a critical path approach, motivation, objectives and research programme to study the European situation;

III — Review of selected elements: V, Ni, As, Se, Mo, Cd, Sb, Hg, Tl, Pb, U;

IV — Analysis of the literature, results, conclusions and recommendations;

V — Natural radionuclides in coals and coal ashes from European conventional power stations and evaluation of a potential environmental impact.

This work is the first of the series and provides a technical basis for the calculations of the minimum and maximum amounts of heavy metals which may be annualy mobilized by the conventional power plants of the European Community.

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