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THE 'PEDIGREE' OF RADIATION ESTIMATES: AN EXPLORATORY ANALYSIS IN THE CONTEXT OF EXPOSURES OF YOUNG PEOPLE IN SEASCALE AS A RESULT OF SELLAFIELD DISCHARGES

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Summary

The increasing interest that is being shown in uncertainties surrounding the estimation of radiation exposures and consequent health effects calls for the development of new ways of representing the degree of robustness of scientific knowledge in this field. This paper describes part of a new notational system - a pedigree coding - for representing the nature and significance of particular sources of imperfection afflicting the production of quantitative estimates. The pedigree coding is applied to the case of estimating radiation exposure of young people in Seascale as a result of Sellafield discharges. Empirical codings, resulting from interviews with relevant specialists, are shown to provide a cogent way of summarising critical sources of imperfection, this in turn giving crucial clues about the way related quantitative estimates should be communicated and interpreted. Lines for further development and application of the pedigree coding system are suggested.

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1. Introduction

Increasing interest has been shown in recent years in uncertainties surrounding the estimation of radiation exposures and consequent health effects in various public policy related problem areas: medical xrays; discharges from nuclear waste reprocessing facilities; possible risks from low and intermediate level nuclear waste storage sites; Chernobyl fall out; natural 'background' radiation effects; and others. To differing degrees in different contexts, prevailing uncertainties introduce ambiguity into what might otherwise be given, and taken, as straightforward quantitative estimates of radiation exposures; and the communication and interpretation of those estimates is rendered problematic. In view of the growing number of instances, both in the public domain and within research communities, where the significance of prevailing uncertainties can have a crucial bearing on decision making, it is important that qualifications about their true nature are always expressed with given quantitative estimates.

There are a number of traditional practices for acknowledging the presence of uncertainties surrounding quantitative estimates. They include the specification of upper and lower confidence intervals to prescribed levels of significance, the representation of the outcome of formal uncertainty analyses, the specification of generous error bars or 'safety margins' on uncertain quantitative estimates, and the addition of various sorts of verbal qualifications. They are each insufficient to take adequate hold of the underlying character of the uncertainties in many important contexts. Notably, the reliability with which confidence limits may be assigned may at times itself be questionable, as might the integrity of any buffer afforded by given safety margins; there are 'unknowns' beyond the reach of formal uncertainty analyses. Verbal qualifications suffer from semantic ambiguity and lack of precision; they are easily isolated and tend to be considered less 'scientific' than more formalised expressions.

In this paper the applicability of a new tool, part of a recently developed notational system (1), for acknowledging the nature and significance of uncertainties surrounding the quantitative estimation of radiation exposures and consequent health effects, will be examined. The relevant part of the notational system to be used in this paper consists of a codified description of the evaluative history of the production of quantitative estimates, called a 'Pedigree'. By reflecting the nature and significance of particular sources of imperfection, it provides an evaluation of the 'quality' of the estimates which, in turn, can be used as a mark of quality assurance, or alternatively as a cautionary signal, by those receiving and using the estimates. The codes represent information elicited either from experts engaged in the production of those estimates, or from study and analysis of the relevant literature.

The pedigree coding given in the present paper extends beyond traditional practices for the expression of uncertainties; indeed, one of its key roles might be to serve as a complement to such practices. As such it might be viewed as a development of attempts made elsewhere to assess the quality of numerical estimates as, for example, in the first official report of the risks posed by the Canvey Island petrochemical complex (2). In that report it was proposed that a simple alphabetical coding (a,b,c,d or f) should be given alongside quantitative estimates of risk in order to reflect their relative degree of robustness (or of weakness) according to their origin - historical record, simulated results, or whatever. The pedigree coding given in table 1, described more fully below, seeks to extend and consolidate the kind of provisional collection of qualitative descriptors recommended in the Canvey Report to create a coherent, consistent and more exhaustive system which can command a proper status in the representation of quantitative estimates.

The present paper is both an illustration and a test of the pedigree coding system given in table 1, drawing on interviews with experts closely involved in the chosen case study: the estimation of radiobiological health risks as a result of discharges from the nuclear installation at Sellafield in Cumbria. During these interviews, the applicability of the system depicted in table 1 to the chosen case study was discussed, and appropriate codings based on that table were elicited, for representing the quality of a given sequence of quantitative estimation of possible radiation induced risks. The paper reports on the performance of the coding system in this context. It is an exploratory illustration, and one whose successful outcome seems to provide a foundation for the future development of more versatile 'pedigree coding' tools for expressing crucial imperfections. Such development holds potential benefit for people receiving or using inherently imperfect information in quantitative form by way of signals as to how such information should be interpreted. It also holds potential benefit for experts originally producing the information, by way of easing dialogue within their own peer communities, and also by way of protection against later criticism arising as a result of inherent uncertainty in the state of development of knowledge at any given time.

2. The 'Pedigree' Of Quantitative Estimates

The form (or design) of the pedigree coding derives from the recognition of three distinct aspects to the process of producing quantitative estimates: a theoretical aspect, an empirical aspect and a social aspect. To draw an analogy with engineering systems, quantitative estimates may be viewed as 'outputs' of a 'machine' working on and transforming 'inputs'. The 'outputs' correspond to the quantitative estimates themselves, the 'inputs' to the empirical aspect, and the 'machine' to the theoretical aspect. The overall validity of the whole process can be judged by appropriately qualified individuals (the judgement of peer communities), according to the standards of the day. This last is more briefly referred to as the social aspect. It follows that the quality (or alternatively, the degree of imperfection) of the product will depend on the quality of the machine, on the quality of what is put in, and on consensus within peer communities that it is doing what it is supposed to be doing.

Closer consideration of possible 'modes' for each of the three aspects - the theoretical, the empricial and the social - will reveal scope to develop a notational system by which it will be possible to 'rate' the quality of any quantitative estimates (accompanied, as appropriate, by associated error bars, confidence intervals or 'safety margins') according to its standing in terms of each of the aspects in turn. Possible modes are given in Table 1, where the first column refers to the theoretical aspects, the second to the empirical, and both the third and the fourth to the social aspect. The final column gives a simple scale of scores which can be used to rate the modes.

A pedigree coding for a given quantitative estimate may be derived from this table by identifying which of the modes of each phase constitutes the most fitting description of that aspect of the process by which the estimate has been produced. Scores between 0 and 4 are used to represent these modes. The pedigree coding then, is a string of four indices

$$P = (i,j,k,l)$$

where i,j,k and l can each take integer values from 0 to 4, the higher the value, the higher the 'quality' on that aspect (and vice versa). The string of characters (4,4,4,4) would depict a quantitative estimate derived from a research field of exceptional maturity, rated highly (a score of 4) on each of the four phases. It would be a mark of high 'quality' to advertise to people receiving and using the estimate. On the other hand, a less well developed field should be described in correspondingly lower rated terms. The string (2,2,2,1), for example, would depict an estimate produced from a field whose theoretical structure is characterised by computational models (a score of 2 in the first place), whose 'data' is calculated (a score of 2 in the second place), which has 'medium' peer acceptance (a score of 2 in the third place), and which is derived from a field which is as yet 'embryonic' in its development (a score of 1 in the fourth place). It would be something of a cautionary signal for people receiving or using the information. A quantitative estimate qualified by the second of these pedigree strings can clearly be seen to be a very different kind of commodity from one qualified by the first.

In some cases the depiction of the mode of a given aspect in terms of a unique numerical code may be problematic. For example, in cases where the data used is partly historic, partly derived by extrapolation, partly by interpolation, and partly by educated guesswork, codes of 1,2 and 3 all come into contention. In these circumstances the full string (with, for the sake of argument, codes of 3,3 and 2 for 'theoretical structures', 'peer acceptance' and 'colleague consensus', respectively) might be written:

$$P = (3,j,3,2) \qquad j = 1,2,3$$

The index j as the second entry of the four-place string signifies the mixed character of the data input. It might otherwise be written:

P = (3,1-3,3,2)

An alternative possibility for dealing with multiple scores for a given aspect would be to consider grounds for excluding some of the contending modes, and using only the most 'significant' in the coding string. For example, continuing the previous illustration, if the data is overwhelmingly derived by extrapolation and interpolation, then that might be deemed ground for selecting a code of 2, and 'over-riding' 1 and 3, this giving:

P = (3,2,3,2)

If no reasonable grounds for exclusion can be identified, then a more satisfactory procedure for dealing with data input of mixed character might be to put a greater emphasis on prudence and follow a 'weak link' rule: opt for the lowest of contending codes for a given place in the pedigree string. This might more effectively fulfill the intrinsic purpose of the pedigree coding in acting as a reliable 'cautionary' or alternatively a 'safe' signal for users. The outcome of this alternative procedure in the case of possible values of 1,2 and 3 for the data aspect would be to choose the value 1, the full pedigree string then being:

P = (3,1,3,2).

Before invoking the pedigree coding in the chosen case study context, the various phases and modes in Table 1 will be described more fully, on the basis of accounts given elsewhere (1,3). Following the traditional scientific methodology, the strongest mode of Theoretical Structure is Established Theory: tested and corroborated; or coherent with other accepted theories. When the theoretical component lacks such strength, and is perhaps rudimentary or speculative, then its constructs must be considered as in a "model", but one which is theoretically based: although still involved in "explanation", such a model makes no effective claim to verisimilitude with respect to reality. A Computational Model is again some sort of formal representation of the elements of a system, but with no serious theoretical articulation of its constructs; the function is purely that of "prediction". This mode characterises the use of high-speed computers for "simulations", where real experiments are difficult or expensive. There can be important studies where neither articulated constructs nor elaborated calculations are present, as in classic "inductive" science. This Statistical Processing can provide no explanation and only a limited prediction; but used in exploratory phases of research, it can yield interesting hypotheses for study. Finally there are situations where data are gathered and analysed, and are structured only by working definitions operationalised through standard routines.

The normative ordering among the modes in table 1 is clear. It is imprtant to recognise here that if, in its present state of development, a field can produce only relatively weak results (as reflected in low scores from the scales in table 1, that should be an occasion neither for shame nor for concealment.

Moving to the Data input aspect, the strongest (classical) mode is Experimental Data. Historic/Field Data; data is somewhat weaker - "accidental" in the sense of being taken as it occurs, and lacking the tight controls or strict reproducibility of experimental data. Weaker still are Data Inputs derived from a variety of empirical sources, and processed and synthesised by different means, not all standardised or reproducible. The numbers are then themselves "hypothetical", depending on untested assumptions and procedures. The modes of Educated Guesses and Uneducated guesses complete the hierarchy of Data input modes.

The social aspects of the pedigree are, as already indicated, to be given in two phases; Peer-Acceptance relates to the particular information under evaluation; and Colleague Consensus describes the state of the field within which the particular problem area lies. These are the phases to which one could turn first, for preliminary evaluations of the quality of quantitative information. The modes of Peer Acceptance range in linear order from Total to None. Those of colleague consensus range from (at best) the characterisation of a field whose high state of maturity is disputed only by cranks; and the (somewhat less robust) characterisation of a field whose high state of maturity is contested also by rebels (rebels having some standing amongst their peers, unlike cranks); to a characterisation of a research field which is more seriously divided (with Competing Schools or perhaps only Embryonic), where there will be little or no security in any piece of quantitative information. Even the sampling of expert opinions, to obtain Educated Guesses, can fail to produce consensus; the user learns the important lesson that scientific ignorance still dominates the problem. At the furthest extreme from scientific orthodoxy, the mode No Opinion is to depict a case where there is simply no cognitive framework or social network in which the quantitative information can make any sense when it appears. This may be from its apparent lack of substance or of interest, or both. Appropriate resolution of a situation where some scientists describe a given field in terms of 'all but rebels', while others describe it in terms of 'competing schools' is perhaps to favour the 'competing schools' descriptor: competing claims being read as a signal that the situation is indeed one of competing schools.

It is important to appreciate the relationship between Peer Acceptance and Colleague Consensus. Thus if there is a strong general consensus and weak acceptance, the quantitative information under evaluation must be judged as of low quality of craftmanship (given trust in the general competence of the field). But if consensus is as weak as acceptance, even such an adverse judgement is not proper; and "ignorance rules again". The degree to which consensus can be weak, even in "matured" scientific fields, is generally underestimated quite seriously by outsiders. Hence low acceptance is liable to be interpreted in a misleading fashion, as a well-founded adverse judgement on the technical information and by extension on its author as well. The "social" aspect has been split into two parts, partly to avoid this sort of error.

Overall, it should be clear how the generally normative ordering of the different modes within each phase enables simple numerical scorings to reflect ratings on each aspect in turn, generating a four-pace numerical coding. The use of this coding will be illustrated below in the context of the estimation of radiation induced health risks caused by Sellafield discharges.

3. The estimation of radiation exposures arising from Sellafield discharges

The Black Report (4) was commissioned through the DHSS in response to media disclosures of an excess in the incidence of leukaemia among children who live near British Nuclear Fuels' nuclear reprocessing operations at Sellafield, in Cumbria, the excess being alleged to be caused by radioactivity contained in discharges from that installation. A major part of the Black Report was devoted to the estimation of radiation exposure of young people in Seascale, its key finding being (para 4.88) that

> "at most less than 0.1 deaths from leukaemia would be expected from the discharges (accidental and planned) from Sellafield to the under 20 year old population of Seascale born between 1945-1975".

There has been considerable controversy in the wake of publication of the

Black Report as to the robustness of this estimate. Whereas some sources describe it as an estimate which may be conservative by a factor of 10 (5), others suggest that it may be a considerable underestimate. The purpose of the analysis below is not to seek to revise the estimate as such, but rather to re-couple it, through an appropriate pedigree coding, to its various crucial qualifications.

It is possible to infer a provisional pedigree coding for the estimate of 0.1 from a reading of the full text of the Black Report, from the research papers from which it was itself derived (5,7), and from various follow-up publications (6,8,9). For the purposes of the research reported in the present paper, such a provisional coding served as a tentative 'hypotheses', the validity of which would be tested in the course of interviews with specialists closely associated with the radiobiological studies. The outcome of these interviews is reported below.

The Black Report's estimate of 0.1 was based on reported discharges from Sellafield, on routine monitoring data, on models of the transmission and transformation of radiation through the environment to known critical sites in the human body, and on models of their pathogenic effects. This series of stages is broadly depicted in Figure 1.

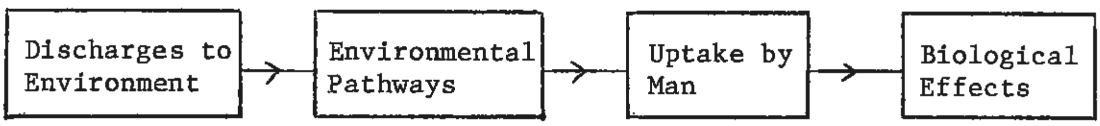

Figure 1. The transmission of possible radiactive contaminants.

The resulting estimate was acknowledged to be surrounded by various sorts of uncertainty, which were referred to in the Black Report as 'remote possibilities':

1. the possibility of there having been undetected discharges that have given rise to doses to the public greatly different to those believed to have occurred.

2. the possibility that ingestion, inhalation and/or absorption of high LET emitters has been grossly underestimated.

3. the possibility that the gut transfer factors for the actinides and other isotopes such as Ruthenium, which are believed to cross the gut wall poorly, are inaccurate.

4. the possibility that the model used to calculate the dose to the red bone marrow is highly inaccurate.

5. the possibility of there being an unusual concentration of unusually susceptible children in the Seascale area.

The report of a more recent committee of inquiry refers to these and other possible sources of uncertainty in rather more pressing terms (9).

4. The 'Pedigree' of stages in the estimation of radiation exposure arising from Sellafield discharges

In order to determine a proper pedigree coding for the key estimate of 0.1, interviews were arranged with specialists who could comment with authority on the estimation of radiation exposures from Sellafield discharges (members of the Committee on Medical Aspects of Radiation in the Environment, a government advisory committee recently appointed through the Department of Health and Social Security; and scientists in the National Radiological Protection Board). During these interviews, the general relevance of the pedigree coding framework (Table 1) to the matter of estimating radiation exposures was discussed, and codes fitting to each of three stages in turn were then elicited. The three stages were: the passage of radio-nuclides from discharges through various pathways in the environment (stage 1); the uptake of possible radio nuclide contamination from the environment giving doses received by young people in Seascale (stage 2); and the possible biological effects of received doses (stage 3). The different experts were interviewed independently, and there was a high degree of agreement in terms of the pedigree codes which they suggested. There follows a summary of the findings.

STAGE 1: The processes whereby radio nuclides from Sellafield discharges may pass through various pathways in the environment were described as being understood in broad theoretical terms. Theoretically based models are used to depict these processes. In the framework of Table 1, a score of 3 would reflect this.

The data input to these models was regarded to be of variable quality, as was the nature of available monitoring data that could be used as a check on discharge records (or on environmental concentrations more generally). The Black Report (4) itself recognises, for example, (para 4.57) that

> ". . . although all monitoring information was made available to the group from as far back as the start of operations in 1952, the quantity and quality of the monitoring data from the earlier years are necessarily less good than the more recent results . . . There are few detailed measurements on crustacea before 1970 and detailed measurements on crustacea and molluscs, including actinide levels have only been carried out since 1977".

The more recent official committee of inquiry COMARE (9) comment (para 5.2)

> ". . . we accept that every reasonable effort has been made to ensure completeness of the information now available to us we feel that the monitoring programme and record keeping for the 1950's were such that we cannot be certain that all releases have now been recognised."

(See also footnotes *1 and *2.) All in all, the nature of the data input to the modelling of radio nuclides through the environment was recognised to be partly historic/ field data, partly interpolation between measurements, and partly educated guesswork (scores of 1,2 and 3). In other words allowing for the full range, the appropriate code for the data entry aspect is j, where j = 1,2,3, or alternatively, adopting a 'weak link' rule for a greater degree of prudence, j = 1.

The degree of peer acceptance of the estimate produced (taking radiobiologists as the peer group) was regarded to be 'medium to high' (scoring 2 or 3), with the integrity of the state-of-the-art disputed only by rebels (score 3) (see also footnote *3).

Overall, the pedigree of estimating the passage of radionuclides from discharges through various environmental pathways can be summarised in the expression

$$P = (3,j,k,3) \qquad (j = 1,2,3;\ k = 2,3).$$

or,

$$P = (3,1\text{-}3,2\text{-}3,3)$$

or, adopting the weak link rule for a greater degree of prudence,

$$P = (3,1,2,3)$$

It depicts a weighted qualification about the possible integrity of the estimation process; a picture neither of total confidence, nor of a scientific wasteland, contrary to what less disciplined commentary might claim.

STAGE 2: The estimation of the uptake of possible radiation contamination from the environment to various sites in the human body was again said to be derived from theoretically based models (score 3). The data input was again described as being a mix of field data (monitoring), interpolation, and educated (or, someone suggested, uneducated) guesswork (scores of 1,2, and 3). The robustness of the field itself was regarded as being more questionable than for stage 1, there being as yet ill understood 'hot particle' issues, uncertainties about the identification of 'critical groups', and a suggested need to reconsider the earlier emphasis on red bone marrow (cf lymph nodes) as the most critical sites. This is indicative of 'competing schools' (scoring 2). The Peer acceptance of the result was regarded as being 'medium to high' (score 2-3).

Overall the pedigree of estimating the uptake of possible radionuclide contamination from the environment can be expressed as

$$P = (3,j,k,2) \qquad (j = 1,2,3;\ k = 2,3)$$

or

$$P = (3,1\text{-}3,2\text{-}3,2)$$

or, adopting the weak link rule

$$P = (3,1,2,2)$$

It is a somewhat more heavily qualified result than that for stage 1, given the loss in experts' (technical) consensus about the state of maturity of the field.

STAGE 3: Estimating the biological effects of radiation doses was generally regarded as being less secure a process than what was involved in the previous two stages. Knowledge in this field has been significantly developed in the contexts, for example, of experiments on animals, and in relation to victims of the bombs at Hiroshima and Nagasaki, but there were regarded to be great problems in producing reliable estimates for man, for low level discharges, and still greater problems for a specific cancer for children. So although the pedigree rating for 'laboratory-animal' estimates might be quite distinguished, the pedigree scores for the extensions and adaptations of these results to the Sellafield context, combined with some direct studies, should reflect a state of somewhat greater under-development. For the theoretical aspect, the modes statistical processing and computational models were deemed the most fitting categories (scores 1 and 2); for the data aspect some field data, some educated guesswork, or worse (score 1,2 and 3). The peer acceptance was described as 'medium to low' (a score of 1 or 2); and there was a view by some interviewees that the field is characterised by 'competing schools', and by others that it is as yet embryonic (a score of 1 or 2).

Overall the derived pedigree code for stage 3 is:

$$P = (i,j,k,l) \qquad (i = 1,2;\ j = 1,2,3;\ k = 1,2;\ l = 1,2)$$

or,

$$P = (1\text{-}2, 1\text{-}3, 1\text{-}2, 1\text{-}2)$$

or, adopting the weak link rule,

$$P = (1,1,1,1)$$

The last coding depicts a marked weakness in this stage of the estimation process.

All in all, the contrast in the derived pedigree codings for each of the three different stages reflects the differing levels of understanding of the processes which constitute each stage and, in turn, brings out crucial differences in the degree of qualification which should be associated with any corresponding quantitative estimates

5. Evaluation and conclusion

One of the initial questions which the exploratory analysis reported above sought to answer was whether or not the pedigree coding system was an intelligible and accessible tool through which experts could cogently express and usefully describe crucial qualifying comment about the relative degree of robustness of quantitative estimates (or quantitative technical information). The experience and findings reported above are very encouraging in their positive exemplification of the utility of the coding system in this respect. In particular, the system is found to succeed in providing an unusually disciplined basis for structuring reflection and dialogue about uncertainties in the production of radiation estimates, reducing ambiguity and providing for improved communication within the scientific community. Specifically, going through the process of eliciting pedigree codings for given estimates encourages, and in some cases forces, keener acknowledgement on the part of scientists themselves of various uncertainties implicit in the production of particular estimates. The rewards derived from this process can be compared with those derived by risk analysts from the process of undertaking a risk assessment, and not only in arriving at a final result. For the authors of the paper, outsiders to the specialist fields at the heart of our chosen case study, the elicitation process made us still more aware than before of the difficulties of producing radiation estimates in contexts of inherent uncertainty.

As to the wider significance of the findings, the pedigree codings assigned to the different stages involved in producing an estimate of the radiation exposures of young people in Seascale as a result of Sellafield discharges encourage a particular directed interpretation of the resulting estimate of 0.1, one which would otherwise be less immediate. The codings express the degree of qualification that is due when communicating and interpreting the findings of each stage, greater qualification being due for the later than for the earlier stages.

An overall implication for this exploratory illustration is that the 'true' number may not be 0.1, for we could only have a high degree of confidence that this were the 'true' number, if the resulting pedigree codings had been higher. At the same time, the relatively low pedigree scorings mean that it is not possible to derive any other estimate than 0.1; the 'true' figure may be much lower, or indeed somewhat higher (see also footnotes *4 and *5).

It is worth repeating at this point that the appearance of relatively low pedigree scoring should be occasion neither for shame nor for concealment. It is merely a true reflection of the quality of what can or has been produced in the face of irremediable difficulties, uncertainties and gaps in scientific knowledge in what is intrinsically a non-laboratory field of inquiry being developed under critical constraints of time and of resources (within the realm of what Weinberg termed trans-science (10)).

A potentially rewarding prospect for the future would be to produce corresponding pedigree codings for other areas of estimating radiation exposures. People receiving or using such quantitative estimates would thereby be given far greater appreciation of their innate character, and considerable insight could result from comparing the relative pedigree scores across different contexts. The pedigree rating for the production of an estimate of radiation dose from a specificed mass of granite, for example, is likely to be very different from that (or those) for estimating exposures in various locations as a result of Chernobyl fall-out, and different again from those of risk-estimates from medical x-ray exposures. Appreciation of these differences is an integral part of knowing how to interpret related quantitative information. To the more technically minded their status should be that of natural andmuch needed extensions to the specification of error bars, confidence intervals and formal uncertainty analyses (refinements which themselves have been slow in gaining wide practice, despite their recognised importance). To the more general audience, their status should be that of a simple rating of quality.

In seeking to produce due pedigree codings in other contexts, refinements and adaptations to the coding framework outlined above may also be realised. These might include, though not necessarily be confined to: more refined definitions of modes for use within expert communities; more aggregate codings for public use; but in all cases to be developed within a disciplined and internally consistent framework. Extensions and wider promotion of such schemes should be welcomed and encouraged by anyone with a serious interest in the legitimate communication and interpretation of estimates of radiation exposures. In many sensitive areas highly robust quantitative estimates cannot be produced, but this should be occasion neither for false definiteness, nor for undue conservatism, about what is known and what is not known. Notational tools for elucidating and differentiating the quality of different radiation estimates in a clear and concise way have much to offer both in clarifying communication within expert communities, and in the fight against flabby rhetoric and illegimate political claim in public debates about radiation risks.

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Footnotes

*1 The existence of previously 'unreported' discharges was confirmed in February 1983 when a former nuclear scientist at Sellafield drew attention to his awareness that uranium of the order of 20-30 kilograms, as compared to the 400 grams previously recorded and incorporated into the Black Report calculations, had been discharged from Sellafield into the atmosphere between 1952 and 1955.

*2 Scientific belief about former discharges is to an extent corroborated by belief by many people who live near Sellafield that the 'exceptional' discharge of radioactive solvent and 'crud' in November 1983 (8) was not such an isolated incident.

*3 It was remarked by the interviewees that the recent disclosures of previously unreported discharges (see footnote 1,), for example, would barely affect resulting calculations of actual exposures, the relatively high 'colleague consensus' score is consistent with this state of affairs.

*4 Before bringing such conclusions to bear on the question of whether or not Sellafield discharges are the likely cause of the observed excess in the incidence of leukaemia among children who live nearby, corresponding pedigree ratings for the state of knowledge about other possible causes (than Sellafield discharges) should be developed.

*5 The estimate of 0.1 has been portrayed in official supporting documentation as being 'conservative by a factor of 10' (4,7): the pedigree codings and subsequent evaluations given in the present paper are not affected by its focus on 0.1, rather than a figure of the order of 0.01, as the key quantitative estimate.

TABLE 1. The pedigree matrix

Theoretical Structures	Data-Input	Peer-Acceptance	Colleague Consensus	Score
Established Theory	Experimental Data	Total	All but cranks	4
Theoretically based model	Historic/ Field Data	High	All but rebels	3
Computational model	Calculated Data	Medium	Competing Schools	2
Statistical Processing	Educated Guesses	Low	Embryonic Field	1
Definitions	Uneducated Guesses	None	No Opinion	0