Does Low Dose Ionizing Radiation Cause Cancer?

The interplay of epistemology and ethics in radiation protection.

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Abstract

Objectives: In order to investigate the relationship between scientific evidence and social commitments this article addresses three questions: 1) does low dose ionizing radiation cause cancer? 2) Is the answer to this question different in a social setting than in a scientific context? 3) What are the consequences of the answers of 1 and 2 for the relationship between epistemology and ethics as played out in radiation protection?

Methods: Conceptual analysis with basis in traditional methods in philosophy of science, in particular theories of causality.

Results: Whether low dose ionizing radiation causes cancer deeply depends on what we mean by *causality*. According to traditional scientific conceptions of causality it is not warranted to say that low dose ionizing radiation causes cancer. Standard approaches in radiation protection, however, imply that there is a causal connection, which is due to the strong social commitment in the field. There is a close relationship between social and scientific conceptions of causality, posing a series of challenges: one being that scientists covertly become moral experts, another one that the general public can be misinformed.

Conclusion: There is a difference between causality in science and in policy making. Mixing these conceptions, as sometimes is done in radiation protection, can be misleading. Whether low dose ionizing radiation causes cancer is a social and not only a scientific issue. As such lay people are warranted to have a say.

Key words: causality, low dose ionizing radiation, cancer, ethics, philosophy of science

Introduction

There is substantial evidence for an association between low dose ionizing radiation and cancer (1-8). Several mechanisms which endorse the association are also well described (8). However, whether low dose ionizing radiation is a modifiable cause of cancer is still open for debate (5,9-11). To establish a definite causal link between low dose ionizing radiation and cancer would require controlled trials where the participants are randomized to ionizing radiation exposure, which is practically and ethically contestable (1).

Accordingly, this article asks three questions. The first question is whether low dose ionizing radiation does cause cancer. The second question is whether the answer to the first question is different in a social setting than in a scientific context. The third question is what the consequences of the answers of the first and the second question are for the role of scientists and lay people in radiation protection?

Conceptions of causation depend on context (12). When assessing scientific evidence, “causation” may have a different and stricter meaning than in social settings, such as health policy making or in law (Mendelson, 2017). In science the traditional function of causality is to explain and predict, whereas in policy making its function is to provide and protect welfare. Science is preoccupied with accuracy, while policy making is concerned with actionability. In law causality is relevant for assessing legal responsibility, and is used to ascribe (legal) guilt, specify penalties, as well to assign compensation for work related health hazards (14). “IN THE LAW, scientific knowledge is used to fix responsibility, not to reveal truth. … Thus, the role of “cause” in the courtroom has a different character than it does in epidemiology or toxicology.” (15). Correspondingly, there may be a related yet different conception of causality in morals, where causality is used to assess (moral) responsibility and ascribe blame.

There are also differences between causality on an individual level, e.g. to show that the cancer of person X is caused by the exposure to radiation of type Y at time Z, and on a group level, e.g. cancer of type R is caused by exposure to radiation of type S under conditions T. Furthermore, there is a difference between testing for causality, i.e. showing that an event is caused by another event, and using causality for practical purposes, e.g. such as assessment of the effects of radiation (16).

This illustrates that the question of whether low dose ionizing radiation causes cancer is a complex question that may have many answers (12,13). It also indicates that there is ample room for bewilderment. The difference in objective and context may result in substantial confusion, e.g. when using figures for radiation protection to estimate numbers of cancers and deaths from low dose ionizing radiation (17) or when "calculating probability of causation of radiogenic cancers"(Kocher et al., 2005).

Although relevant to a wider field, this article is restricted to investigate whether low dose ionizing radiation causes cancer within a traditional scientific conception of causation, and to address the question in a particular social context: radiation protection.

Whether there is a causal relationship between low dose ionizing radiation and cancer depends on what we mean by "causal relationship." I will first investigate whether there is a causal relationship in a deterministic sense before investigating probabilistic conceptions of causality. I will argue that there is no causal connection between low dose ionizing radiation and cancer in traditional scientific conceptions of causality. However, social conceptions of causality may still be relevant in radiation protection. If this is so, then persons and groups with social commitments should have a say on cancer causation, and not only experts.

Materials and Methods

Although referring to empirical studies, this is a theoretical study, applying a conceptual analysis based on standard methods in analytical philosophy and in philosophy of science. The analysis of causality and uncertainty is based on traditional theories in philosophy of science. References to the particular perspectives and theories are provided continuously in the text.

As part of the study several literature researches have been performed. PUBMED was searched[1] for systematic reviews, primary studies, reports and books. As few studies on causality in radiation protection was found nested search and snowballing was performed.

Results

No deterministic causality

The *locus classicus* for deterministic causation in the life sciences is the Henle-Koch-postulates for causality (19). According to these postulates, in order for a phenomenon to be a cause of a disease, the phenomenon has to be present in every case, i.e., without the phenomenon, no disease. Furthermore, the disease has to occur every time the phenomenon is present. That is, the phenomenon has to be both a necessary and a sufficient condition for the disease to occur. This is a strong claim, and it has therefore been called "strong causation." Applying the Henle-Koch postulates to low dose ionizing radiation we would have:

1. All persons exposed to ionizing low dose radiation would get cancer, but nobody who is not exposed.

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[1] Search strategy: (("low dose ionizing radiation" or (("radiation" or "exposure") and ("x-ray" or "radiology")) and ("cancer" or "cell alterations" or "oncology"))[Title/Abstract]) AND (causation or causality or cause)[Text Word]

2. The low dose ionizing exposure must be able to be differentiated from natural exposure, such as background radiation.
3. The low dose ionizing exposure should cause cancer when exposing a healthy person.
4. Traces of radiation must be identified in the diseased person.

It is quite clear that low dose ionizing radiation does not satisfy these criteria. First, low dose radiation is not a necessary and sufficient condition for cancer, as noticed above. Furthermore, low dose radiation from human exposure may be difficult to differentiate from background radiation, and so far it is difficult to identify radiation exposure in cancers.

For high dose (typically above 1 Sv), we experience deterministic effects, and would expect that the claim that ionizing radiation causes cancer holds. However, even with high doses, cancer does not always occur,[2] and cancer can occur also without high doses of ionizing radiation. That is, (high dose) ionizing radiation is not a together necessary and sufficient condition for cancer. Noticeable, even Koch realized that these criteria were too strict for any practical conception of causality in health care (20).

Nevertheless, we can look for "weak causation," e.g., we can ask whether radiation is a necessary, but not sufficient condition for cancer, i.e., whether it is a *sine qua non* for cancer? This can be called "causation by absence". We can ask "What would have happened if exposure to low dose ionizing radiation had not occurred?" If the answer is: "then the cancer would not have come about", there would be a causal relationship between low dose ionizing radiation and cancer. The basic idea is that a causal claim can be explained in terms of *counterfactual* conditionals of the form "If C had not occurred, E would not have occurred," where C is what is considered to be the cause and E is the effect. The question of what would have happened if the ionizing radiation had been absent is relevant because by removing the necessary condition, we could prevent cancer. However, as cancer occurs without low dose

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[2] Other detrimental health effects may occur, such as cell damage.

ionizing radiation, it is not a *sine qua non*. Hence, (low dose) ionizing radiation is not a necessary condition for cancer.

Another traditional conception of causality is to define it in terms of *sufficient but not necessary* conditions. This can be called "causation by presence," as causation is ensured by the presence of the "cause." In ordinary language and in epidemiology sufficient conditions are conceived of as causes, because whenever the condition occurs, the "effect" will also occur (Rothman and Greenland 1998). However as alluded to already, cancer does not occur every time when exposed to low dose ionizing radiation, and thus, radiation is not a sufficient condition for cancer.[3]

In principle low dose ionizing radiation may still cause cancer in a deterministic way, e.g. when cancer depends on other conditions in addition to low dose ionizing radiation (e.g., a component cause model). There may be unknown biological or biomolecular factors that, when combined with ionizing radiation, would be sufficient and necessary for the development of cancer. Low dose ionizing radiation could for example be an *insufficient* but *necessary* part of a *sufficient* and *necessary* condition for cancer. However, the insufficient, but necessary conditions that together with low dose ionizing radiation are necessary and sufficient for cancer are yet unknown.

Another example of complex deterministic conditions for causation is that low dose ionizing radiation is an *insufficient and necessary part of an unnecessary but sufficient* (INUS) condition for cancer (21). Here the low dose ionizing radiation would be an element in an altogether sufficient, but not necessary constellation of conditions. The low dose ionizing radiation is not sufficient alone, because radiation can appear without resulting in cancer. Neither is the low dose ionizing radiation (as well as the other conditions) necessary for

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[3] Even more so, cancer does not occur every time with high dose exposure either, although other deterministic effects may be seen. It is worth noticing that there are very few instances in health care where we know the sufficient condition for a disease. There are also many interpretations of what is meant with "necessary" and "sufficient," but this is beyond the scope of this article.

cancer, because there are many other paths to cancer. Moreover, we do not know the (insufficient and necessary) parts that together with low dose ionizing radiation are sufficient, but unnecessary for cancer, i.e., so far there is no INUS-type causation between low dose ionizing radiation and cancer.

Altogether, this makes it difficult to corroborate a deterministic relationship between events such as low dose ionizing radiation and cancer. Hence, in a deterministic perspective, low dose ionizing radiation does not cause cancer. Even more, high dose ionizing radiation does not cause cancer either, as cancer is not a result of radiation in any of the traditional conceptions of deterministic causation.

Although we cannot say that low dose ionizing radiation causes cancer in a deterministic context, we may of course talk about low dose ionizing radiation causing cancer in a probabilistic perspective. We do so based on the assumption of stochastic effects from low dose ionizing radiation, i.e., effects that are random but are related to cancer in some way (2-3). Stochastic effects are difficult to account for on an individual level, but may be investigated on an overall level, e.g., by epidemiological studies.

Non-deterministic causality

Causality is oftentimes characterized by a probabilistic relationship between what is considered to be cause and effect. E.g., there is an increased probability of cancerous events when exposed to low dose ionizing radiation of specific kinds. This kind of probabilistic conception is expressed in the (first of the) seminal nine “viewpoints” of Bradford Hill from which to study the association of two variables in order to claim causality (22), see Table 1. Accordingly, hypotheses on causal connections between low dose ionizing radiation and health effects can be formulated and tested by epidemiological studies.

Probabilistic conceptions of causality[4] have many pros, but also some cons. They say little about the (relative importance) of its underlying factors (12) and give no guidance to where delimiting causality from mere association. There is a strong association between having grey hair and cancer, but grey hair is hardly the cause of cancer. How strong does the association between exposure to low dose ionizing radiation and the occurrence of cancer have to be in order to qualify for causality? Does the limit vary with the type and severity of cancer? These are normative (and not only descriptive and scientific) questions. Where we set the limits between causality and mere association tends to depend on social commitment. Weaker associations are more easily accepted as causes for severe preventable diseases than for ordinary conditions without significant implications.

It can be argued that the social contingency of probabilistic causality renders it "unscientific" and relativistic, and indicates that we should stick to associations and stop talking about causality altogether (26). Again, the rooster's craw at the break of dawn every day does not make the rooster causing the sun to rise (27). Although the probabilistic conception of causality gives no indications of underlying deterministic conditions, which gives rise to the co-variation (28), it still warrantless presupposes such conditions.

Hence, sticking to Bradford Hill's nine viewpoints (in Table 1) on causation, there are challenges with claiming a causal connection between low dose ionizing radiation and cancer. First, the strength of association is weak. The reproducibility of high quality research results is low, because decisive experiments either are difficult or unethical to conduct. The specificity of the association is low, as background radiation and other factors may result in cancer as well. Ascertaining the temporality criterion may be challenging, due to the long time span and uncertainty about mechanisms. Accordingly, the experimental evidence is low.

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[4] Probabilistic conceptions of causality are oftentimes called "black box causality." (12)

Many causalities – no cause

There are of course other conceptions of causality, such as mechanistic and dispositional conceptions of causality. However, this brief review of some of the traditional conceptions of causality is sufficient to illustrate that causality can mean many things, and that the answer to whether low dose ionizing radiation causes cancer is contingent to our conception of causality. Table 2 summarizes the conceptions of causality discussed above. When associations are weak and available evidence is scarce, the limitations with the various conceptions to causality become prominent.

[Table 2]

This leaves us in an unpleasant state. Until more scientific evidence becomes available, it is difficult to defend a causal connection between low dose ionizing radiation and cancer. I.e., it is uncertain whether low dose ionizing radiation causes cancer. But what do we do when there is a potentially hazardous effect of radiation that people are exposed to, such as described in the empirical studies referred to at the outset of this article? One alternative is to investigate alternative conceptions of causality, e.g., causality for practical purposes which take into account our social commitments, such disease prevention as expressed in radiation protection. This is a plausible approach, as assessment of the strength of association is an inevitable normative aspect of probabilistic causation, as already pointed out.

Probability of causality

One practical approach is to estimate radiation related cancer risk (1,5,17). High risk estimates expresses a higher probability of causality. However, cancer risk from low dose ionizing radiation can be calculated in many ways and involves a series of judgments and assumptions (13). Moreover, the health effect from radiation is heavily dependent on how we classify "radiation effect," e.g., cancer incidence, morbidity, mortality, exposure-induced cancer incidence (REIC) exposure-induced death (REID), excess cancer deaths (ECD), years of life lost per unit dose (YLL), and life lost/radiation-induced cancer death (YLLRIC). There is no true classification of radiation health effect, as the choice of measure depends on our social commitments: to help or protect people.

Correspondingly, a cancer incidence can be assigned to low dose ionizing radiation, such as in *assigned share* and *probability of causality*. The *assigned share* value is expressed as excessive relative risk divided to the relative risk (ERR/RR) based on risk models of organ-specific cumulative equivalent dose (14). The cause of cancer can also be *attributed* to low dose radiation prospectively based on similar risk models.[5]

Risk models provide us with useful estimates, and sensitivity analysis presents important quality assessments. Hence, *assigned share* and *attribution* of health effects, such as cancer, to low dose ionizing radiation give useful guidelines for preventive measures. They are, however, based on a series of assumptions and judgments. As the real probabilities are unknown, and many of the models, estimates and extrapolations cannot be tested (falsified) empirically (29), they are, strictly speaking, *scientifically based speculations*. Making models, estimates, and extrapolations is part of normal scientific activity, and follow traditional internal norms of science (30). However, if these models, estimates and extrapolations are never subject to empirical testing, or if their assumptions are covert, unquestioned or normative, we infringe traditional *internal norms* of (empirical) science, such as testability, reproducibility, and openness (30). The danger is, on the one hand, that social commitments and norms sneak in and "contaminate" or bias basic scientific concepts, such as causation, and, on the other hand, that risk estimates are presented as value free scientific facts (12).

[5] Other parameters may be used, such as "inferential weight," "attributable fraction," "etiological fraction," "attestable cause" etc. However, such measures are based on scientists' value judgments.

Of course, our assumptions, models, and estimates may be justified by the social commitment: to protect people from potential harm (19). They may be the best we have in addressing and handling exposure to ionizing radiation (31).[6] However, letting the justifiable social commitment sway or "encroach" core scientific concepts, such as causality, may generate significant confusion, e.g. scaring people by presenting risk estimates as risks and causal connections, or imperfectly making scientists experts in ethics and health policy making.

Hence, there is no causal connection between low dose ionizing radiation and cancer in any traditional scientific conceptions of causality. Science-like approaches, such as risk estimation, involve value judgments and are driven by social commitments. They may confuse a social conception of causality with a scientific one.

Social conceptions of causality in radiation protection

Despite the lack of causality in a traditional scientific sense, we act as if there is a causal relationship in practice. Principles for radiation protection and protective measures are established as if low dose ionizing radiation causes cancer (and other diseases).[7] This is because the concept of causality is different in policy making than it is in science. In science the function of causality is to explain and predict, whereas in policy making its function is provide and protect welfare. Additionally, the debate on whether low dose ionizing radiation causes cancer also has affinities to causality in law, especially with respect to compensation programmes (14). Here causality is relevant for assessing legal responsibility, and is used to ascribe (legal) guilt and specify penalties. Correspondingly, there may be a related, but yet

[6] The social norms in radiation protection are easily identified in the principles of ICRP: justification, optimization, and individual dose limits (39).
[7] E.g., the precautionary principle is a norm for where to place the burden of proof when we are uncertain. It engrosses a bias of caution and safety (52).

different, conception of causality in morals, where causality is used to assess (moral) responsibility and ascribe blame.

It is well known that scientific conceptions of causality inform and influence causality in law, morals, and policy making. In radiation protection the opposite seems to be the case: there is an influence from social conceptions of causality (legal, moral and in policy making) that affects science. This is challenging if one believes that science can and should be demarcated from other kind of social activities. However, it can also be challenging from another perspective: There is a danger that we unnecessarily aggravate a health problem (32). Although the association with cancer may call attention to an otherwise important health problem, it may also result in unnecessary fear of low dose ionizing radiation and cancer. This relates to a second moral challenge: risk aversion. Leading attention to potential harmful effects of low dose ionizing radiation *may* contribute to a general risk aversion (17,32-37).

Discussion

This article started out asking whether there is a causal relationship between low dose ionizing radiation and cancer and has shown that the answer deeply depends on what we mean by *causality*. Investigating some traditional scientific conceptions of causality indicates that, so far, we are not entitled to say that low dose ionizing radiation causes cancer. Even more, when the social commitment of radiation protection feeds into the scientific conception of causality, confusion occurs, scientists may come to operate outside their field of competence (as undercover moral experts) and the public may get frightened (17, 32-35). Hence, one could quote Bertrand Russell: “The law of causality, …, is a relic of a bygone age, surviving, like the monarchy, only because it is erroneously supposed to do no harm.” (38). Only, in radiation protection it can do some harm.

There are of course other concepts of causality than those addressed here, both within and outside science, which could have been addressed as well. However, the main conceptions of scientific causality have been addressed, and they all give the same conclusion.

This study has also revealed that a typically scientific question, i.e., whether low dose ionizing radiation causes cancer, involves moral issues on many levels. As we have seen, the choice between several conceptions of causality, and where to set the limit between mere association and causality, which models to use, and how to attribute or assign risk or causality depends as much on social commitment as on scientific measurement.

These findings urge the discussion on how to delimit science and society: A) Where are the thresholds to how much social commitments can influence or infringe scientific concepts, such as causality? B) What is the role of scientists in attributing causality to low dose ionizing radiation and cancer, e.g., versus the role of lay people?

Science and society in the reign of uncertainty

As argued, radiation protection is an area where the traditional demarcation between science and society is challenged. Scientists' concept of causality is influenced by social commitments, and scientists enter social debates about welfare protection as "experts." One reason for this is the level of uncertainty to whether and how much low dose ionizing radiation advances cancer. This poses the question: are scientists out of line?

One way to address this challenge could be to avoid all causality talk as long as evidence is absent (18), and strictly stick to terms like "co-appearance", "association", and "risk estimates." We could say: "To our knowledge, low dose ionizing radiation does not cause cancer, but for protective purposes we have estimated the cancer risk to be …" This would restrict causality to science, and potentially protect it against social infringement.

Correspondingly, one could classify uncertainty into various classes or realms (40-46), and to delimit scientists from social realms, or give them special tasks. One such example is given in what has been called the matrix of uncertainty, illustrated in Table 3 (42).

[Table 3]

A second approach would be to say that the science/non-science divide is archaic or utopian. In modern society science and society are so interwoven that to distinguish between the scientific and the social, has become pointless (47-49). There is a co-evolution of science and society, and concepts like cancer, causation, and risk cannot be kept purely descriptive. They are normative as well. This eradication of the demarcation between science and society grants scientists new roles.

A third approach is to acknowledge the strong symbiosis between science and society (48), but to argue that some core concepts are still purely descriptive. These purely scientific concepts, such as causation, feed into the normative debates on application, consequences, and protection. The relationship between description and prescription in the debate on causality in radiation protection can be illustrated in figure 1.

[Figure 1]

There are pros and cons with all of these approaches, which are intensely and extensively debated in the literature. To enter this debate here would be beyond the scope of this article. However, as far as radiation protection is based upon or influences conceptions of causality, and thus operating on the border between science and society, we are forced to reflect critically on these issues.

Who decides on causality

As causality in radiation protection has a poor scientific basis, and at present is as much a social as a scientific concept, we are urged to address the question of *who decides*? Who is entitled to make assessments on causation and risk, and who can make decisions on protective measures, as well as issues of compensation? Although scientists are trained in modelling, extrapolating and estimating; decision makers, policy makers, the general public, and those who will face the consequences of a technology could be as qualified to appraise the parameters for the assessment, e.g., the values of life, risk acceptance, health, pain, and disease (47).

Because facts are uncertain, systems are complex, values are involved, and decisions are urgent, a new and extended "post-normal science" has been called for (50-51). Below the traditional level of scientific evidence, scientists guess and believe like all other people. E.g. whether one adopts and supports the Linear-Non-Threshold (LNT) model or the Threshold Model (32), is strongly founded on belief, as no decisive empirical evidence exists. Norms and values are entered (52) and the peer community should be extended beyond scientific experts. Accordingly, scientists have no privileged position in assessing risks and recommending preventive measures. When scientists go beyond the limits of their knowledge, they enter the realm of policy making (49), which comprises another realm of knowledge and norms. In policy making, scientists are not entitled a privileged say.

This indicates that Bertram Russell was wrong when he said: "The scepticism that I advocate amounts only to this: (1) that when the experts are agreed, the opposite opinion cannot be held to be certain; (2) that when they are not agreed, no opinion can be regarded as certain by a non-expert; and (3) that when they all hold that no sufficient grounds for a positive opinion exist, the ordinary man would do well to suspend his judgment." (Russell 1928) When it comes to legal, moral, or political conceptions of causality, the scientist has no primacy. In moral matters lay people may be experts as much as scientists (47).

Comment [b1]: Russell B. Sceptical Essays. London: George Allan & Unwin Ltd; 1928

Hence, the assessment of the health effects of (low dose) radiation touches upon basic topics in the philosophy of science, such as what are the criteria for causality, what is evidence, where are the limits between science and policy making, and who should have a say in cases of uncertainty?

New empirical evidence may of course in the future show that there is a causal connection between certain infectious factors and cancer, for example new radiation-sensitive biomarkers of cancer. Moreover, other perspectives from philosophy of science and ethics may reach different conclusions. Here I have only referred to a traditional methodology.

Conclusion

We can now answer the initial questions: 1) low dose ionizing radiation does not cause cancer in the scientific sense of causality. 2) Although low dose radiation is (yet) no scientific cause of cancer, it is a cause in the social meaning of causality, i.e., in the context of radiation protection. 3) The consequences of 1 and 2 are a) that social conceptions of causality can influence scientists' conceptions of causality as well as challenge the traditional science/non-science divide, e.g., when estimates and science based extrapolations and speculations are presented and discussed as scientific facts, without acknowledging the assumptions, models, and presuppositions that are the basis for these estimates and speculations. b) Scientists can unwarranted become "moral experts," and c) the public is justified in being informed and to participate on issues of radiation protection.

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Table 1 **Bradford Hill's nine "viewpoints" of causality. From** (22).

Strength of Association	the stronger the association, the less likely the relationship is due to chance or a confounding variable
Consistency of the Observed Association	Are results reproducible? Has the association been observed by different persons, in different places, circumstances, and times? Do similar findings exist in other studies with different populations, countries, situations, or periods?
Specificity	Whether an association is limited to specific persons, sites and types of disease, and whether there is no association between the exposure and other modes of dying.
Temporality	The exposure of interest must precede the outcome by a period of time consistent with any proposed biologic mechanism.
Biologic gradient	There is a gradient of risk associated with the degree of exposure (dose-response relationship).
Biologic Plausibility	There is a known or postulated mechanism by which the exposure might reasonably alter the risk of developing the disease.
Coherence	The observed data should not conflict with known facts about the natural history and biology of the disease.
Experimental evidence	The strongest support for causation may be obtained through controlled experiments (clinical trials, intervention studies, animal experiments)
Analogy	Judgment by analogy, can be acceptable. "With the effects of thalidomide and rubella before us we would surely be ready to accept slighter but similar evidence with another drug or another viral disease in pregnancy".

Table 2 Conceptions of causality with regards to whether they are deterministic or non-deterministic.

Deterministic conceptions of causality	**Non-deterministic causality**
Hard causality: Necessary and sufficient conditions Weak causality: - Sufficient conditions - Necessary conditions - Component cause model*:* o *Insufficient* but *necessary* part of a *sufficient* and *necessary* condition o *INUS*	
	Probabilistic (Bradford Hill) Black box epidemiology

Table 3 Uncertainty typology, after (42)

Probability \ Possibilities	Known outcome	Unknown outcome
Known probability	**Risk** • Risk assessment • *Optimizing models* • *Expert consensus* • Cost–benefit analysis • Aggregated beliefs	**Ambiguity** • **Interactive modelling** • ***Participatory deliberation*** • ***Focus & dissensus groups*** • **Multicriteria mapping** • **Q-method, repertory grid**
Unknown probability	**Uncertainty** • **Interval analysis** • **Scenario methods** • **Sensitivity testing** • ***Decision rules*** • ***Evaluative judgement***	**Ignorance** • **Monitoring & surveillance** • **Reversibility of effects** • ***Flexibility of commitments*** • ***Adaptability, resilience*** • ***Robustness, diversity***

Figure 1 The relationship between descriptive and prescriptive aspects of the assessment of whether low dose radiation causes cancer from a traditional perspective.