Environmental Science and Policy 92 (2019) 152–160

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Chernobyl science and politics in Belarus: The challenges of post-normal science and political transition as a context for science–policy interfacing

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ARTICLE INFO

Keywords:
Chernobyl accident
Radioactive contamination
Risk management
Knowledge politics
Science-policy interfaces
Post-normal science

ABSTRACT

Due to high uncertainties and "no-knowledge" spots, and because of their highly politicised contexts, Chernobyl-related environmental and health issues represent an ideal post-normal science situation (PNS). The history of Chernobyl policy and science in Belarus started with a short period in the early 1990s, when due to a political situation, the parliament adopted adaptation and rehabilitation policies and legislation that adhered to the precautionary principle. Soon after, it was recognised that this precautionary action was not economically viable, and although the declared policy approach remained the same, it was eroded by the modified institutional environment and by the implementation practices, which were branded as evidence-based and endorsed by international organisations. To achieve this, Belarusian government channelled public funds to a limited number of selected research organisations affiliated with governmental bodies in charge of Chernobyl affairs, removed non-state actors from Chernobyl research, and monopolised data collection, thus eliminating concurrent knowledge production. To understand the science-policy interfaces (SPIs) developed over Chernobyl issues and their transformation in changing policy situations and in this PNS context, we used and compared analytical perspectives provided by two frameworks assessing SPIs. We also noted a very limited exchange with and support from international scientific communities to promote the development of strategic knowledge.

1. Introduction

Nuclear power plants (NPPs) have been branded by nuclear industries and many governments as the safest method of generating energy. NPPs operate in keeping with the highest possible safety standards, and if nothing wrong happens then everything seems fine, at least at the operational stage. Given the scale of the industry, the accident rate is low. During the entire history of NPP generation, only two level 7 (major) and one level 6 (serious) accidents, based on the International Nuclear and Radiological Event Scale (INES), have occurred. However, these disasters (Chernobyl [USSR, 1986], Fukushima [Japan, 2011], and Kyshtym/Mayak [USSR, 1957]) were of a global magnitude, and a quick review of some of the lower-ranked events gives the disturbing impression that luck was the only barrier against a major disaster occurring. That said, NPP-associated radioactive fallouts affecting large areas and hundreds of thousands of people are likely to reoccur in the foreseeable future. The Chernobyl and Fukushima examples further suggest that regardless of nations' preparedness to face major disasters, the political systems they have in place, and the levels of science and technology they possess, there are no warrantees against errors, mismanagement, and miscommunication. The lessons learned from the governance of the Fukushima and especially the Chernobyl accidents are unique and should be taken seriously. The science–policy interactions regarding these highly complex and uncertain problems represent one of the most important and intriguing issues that must be understood to make sense of these disasters and their aftermaths.

The Chernobyl accident of April 26, 1986 was arguably the greatest human-made environmental disaster (Dixit, 2016), with large areas —primarily in Belarus, Russia, and Ukraine—exposed to radioactive fallout. Once the USSR collapsed in 1991, Belarus had to implement its own policies to manage the environmental and economic risks associated with the Chernobyl aftermath, and it needed to create a whole research infrastructure to inform its policy and management actions. By the end of the 1990s, the Chernobyl issues started to receive less public attention and to slip down the national political agenda. From the early 2010s onward, research and radioactive monitoring budgets were cut yearly (MESRB, 2016), while several research departments and entire organisations were closed.

Against this backdrop, we will analyse the ability of Belarusian "Chernobyl science" (i.e. the scientific communities exploring the issues

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https://doi.org/10.1016/j.envsci.2018.11.024
Received 29 January 2018; Received in revised form 29 November 2018; Accepted 29 November 2018
Available online 07 December 2018
1462-9011/

related to radioactive contamination) to produce credible, relevant, and legitimate knowledge by reflecting on transition of "Chernobyl science" and "Chernobyl politics" (i.e. the political discussions and processes related to the management of the Chernobyl aftermath) from the late 1980s through 2017. The fascinating aspect of this case is that we witness a combination of a post-normal science (PNS) context and a top-down political regime, which is a frequent occurrence but is rarely explored in the literature on science–policy interfaces (SPIs). This further urges us to explore the ways in which the conceptual frameworks addressing SPIs work in such contexts.

Exploring the social dimension of "Chernobyl science" and its engagement with politics, we extend the scope of the study from the micro level (research groups and individuals)— researched mostly through interviews—to the macro level—national policy-making and knowledge production systems. Our discussion and conclusions on SPIs in the context of Belarusian "Chernobyl politics" are based on the mapping of actors and institutions, as well as their transformations over the past 30 years; two case studies addressing specific PNS contexts; and a brief bibliometric analysis of Chernobyl-related publications produced by Belarusian scientists.

2. Knowledge in post-normal science contexts and science–policy interfaces

2.1. The understanding and management of incomplete and contested knowledge

Exploring the problem of policy-making under incomplete, highly uncertain, and contested knowledge, Funtowicz and Ravetz (1990) challenged the very notion of "hard facts" being applicable to situations in which "scientific evidence" (e.g. coming from physics) needs to be interpreted in terms of biological or social systems. They specifically pointed out that "oncology, epidemiology and even radiological protection, are radically different from nuclear physics and heat engineering", as they are unable to provide clear answers to build "a closed set of rules for puzzle-solving" (ibid., 66)—that is, spreading beyond the framework of *normal science*, as formulated by Kuhn (1962). They also brought forward *extended peer review*, which would involve not only scientists but also stakeholders, including politicians, who may be using, or may be affected in any other way by the use of, science when policy-relevant issues are at stake (Funtowicz and Ravetz, 1992).

PNS enjoyed a lot of attention from environmental and related researchers as both a research and a communication strategy. In particular, it was empirically observed (Farrell, 2011) that extended peer review is better equipped to analyse some types of late-industrial scientific problems (e.g. polluted mega-sites) than conventional peer-review methods, that the political and social relevance of such problems is the inherent value criterion, and that the combination of technical and political judgement needed to describe this value leads to the democratisation of scientific expertise. Wesselink and Hoppe (2011) further argued that PNS "has been much more successful as sensitizing concept than as fully fledged theory or as heuristics for the governance of concrete problems. . . as there is no scientific way to 'solve' unstructured societal problems" (Wesselink and Hoppe, 2011, p. 406).

The structuring of societal problems is another way to frame the engagement of policy-makers with scientific knowledge. Put forward by Hisschemöller and Hoppe (2001), this framework recognises *structured, unstructured*, and *moderately structured problems*, depending on how certain the relevant knowledge about the problems is and how far they are from the established consensus on relevant norms and values. Problems that are unstructured—or "wicked" (i.e. how Rittel and Webber, 1973 referred to highly uncertain and contested issues)—need learning as a policy process, whereby scientists signal problems, and knowledge is needed to evaluate the perspective of intervention (Hisschemöller and Hoppe, 2001).

Approaching incomplete knowledge management from the perspective of technology assessment, Stirling (2012) identified four instances of knowledge conditions as regards the state of knowledge about identifiable likelihoods and possibilities: *risk*, *uncertainty*, *ambiguity*, and *ignorance* (i.e. an "unknown unknowns" situation with uninformed alternative pathway choices ahead). The situations with ambiguous understandings of possibilities bring about massive challenges and confusion (e.g. when the actual impacts occur) and an established vision of what harm actually means is not yet in place, while the situations of ignorance require that eyes and options be kept open, which is an unfamiliar mode of operation for many public bodies and business organisations (Stirling, 2012). An important point relates to the oversimplification of expert advice, which is to be avoided so that decision-makers are held accountable for their decisions (Stirling, 2012).

2.2. Science–policy interfaces and their properties and design

Approaching SPIs from a broader environmental governance perspective, van den Hove (2007) defined them as "social processes which encompass relations between scientists and other actors in the policy process, and which allow for exchanges, co-evolution, and joint construction of knowledge with the aim of enriching decision-making" (p. 815). Bukowski (2017) further observed that being a social process, the construction of SPIs is driven by factors such as the role of science in the society and by the openness of academic communities to the broader society. A specific knowledge production and exchange system can, therefore, be mapped on a continuum from "fortress science" to autonomous scientific assessments, politically engaged scientific assessments, extended peer communities/democratic science, and, ultimately, co-production (Stirling, 2012). Approaching this issue from the policy-making perspective, Pielke (2007) recognised similar choices for scientists to become engaged with this process: the pure scientist, the science arbiter, the issue advocate, and the broker.

Analysing the effectiveness of knowledge systems in supporting sustainability, Cash et al. (2003) argued that in order for it to have a sufficient impact on societal processes, scientific information needs to be credible, salient, and legitimate (CRELE). Effective systems also ensure "boundary management" between knowledge use and production, taking care of functions such as communication, translation, and mediation; these functions are often carried out by "boundary organisations" that also manage the co-production of knowledge and information through the use of "boundary objects" (ibid.). Boundary organisations are formal organisational structures bridging research and policy (Guston, 2001); they are supposed to enjoy credibility both in political and scientific communities (Hisschemöller and Sioziou, 2013).

Enst, van et al. (2014) specifically explored the productivity of SPIs and connected the CRELE components of knowledge with the structuredness of the policy problem and consensus about norms and values. Sarkki et al. (2014) paid attention to the trade-offs between the CRELE components, such as *personal time* (scientists and practitioners interfacing vs. doing their core activities), *clarity–complexity* (simple message vs. uncertainty communication), *speed–quality* (timely outputs vs. in-depth analysis), and *push–pull* trade-offs (supply- vs. demand-driven research). Noting that solutions need to be found in relation to a specific context, they emphasised the unavoidable existence of trade-offs (ibid.). Seeing in CRELE an approach coming from an intra-scientific perspective, Dunn and Laing (2017) argued for its limited value for policy-makers and put forward applicability, comprehensiveness, timing, and accessibility (ACTA) as criteria that better reflect the effectiveness of scientific research for decision-makers. PNS situations and top-down governance setups are still new grounds for CRELE and ACTA, especially in terms of trade-offs and chosen compromises.

2.3. Methodological framework and specific research objectives

Due to their complex nature, with high uncertainties and even the involvement of abundant "no-knowledge" spots, and because of their highly politicised contexts, Chernobyl-related environmental and health issues represent an ideal PNS situation. In terms of policy questions, these issues are spread across the range from moderately structured to unstructured ones (Hisschemöller and Hoppe, 2001), and within Stirling's (2012) domains of "ambiguity" and "ignorance". Recognising this, we explored the transition of Chernobyl SPIs in Belarus in terms of the preparedness of policy and knowledge production systems to embrace open-minded and transparent operating models. To sharpen the analytical focus, we chose two specific policy questions that are reflective of different governance challenges and scales:

- Setting safe exposure thresholds to ionising radiation
- Framing and assessing the impact of low levels of radiation on human health

To understand the SPIs developed over these issues and their transformation in changing policy situations, we used and compared analytical perspectives provided by the CRELE (Enst, van et al., 2014) and ACTA (Dunn and Laing, 2017) frameworks. This comparison also gave us an opportunity to reflect on their applicability in a top-down and self-sufficient science policy context such as Belarus.

3. Science–policy interactions over chernobyl-related issues in Belarus

3.1. The science–policy context

When Belarus became independent in 1991, Chernobyl-related issues were still among the top political priorities due to the high awareness of the population and the country's relatively transparent elective democracy (Stepanov, 2010). A massive governance and research organisational infrastructure was created to support adaptation and rehabilitation measures in the aftermath of Chernobyl. (Chernobyl-related legislation is described in Appendix B.).

Following shifting political priorities and the rapid change of socioeconomic and governance systems, the organisational structure was under nonstop reorganisation as well. (This organisational structure, as of 2016, is summarised in Fig. 1.)

The most radical shift in political priorities came in 2009, when the president announced that the period of overcoming Chernobyl's aftermath was over and that economic life needed to return to the contaminated areas (Institute of radiology, 2013). A quick sequence of events followed: Between 2009 and 2010, the entire body of relevant legislation, regulation, and standards was revised in keeping with the overall aim of relaxing the regime, lowering thresholds, cutting expenditure, and so on. The targets and language of the *2011–2015 State Program for the Overcoming…* were revised and reset to shift attention from "overcoming" towards "restoring" (Annex B, State Program…, 2010), and a broad range of information products promoting options for safe living in contaminated areas was developed.

State actors concerned with Chernobyl were scaled down; for example, in 2006, the Committee for Chernobyl Affairs was reorganised into a regular department at the Ministry for Emergency Situations, which also greatly reduced its institutional weight. Use of whole-body counters of effective doses (which is the only method of directly measuring actual radiation intake) had already been recognised as a medical procedure (and had, therefore, been brought under licensing requirements applicable to the medical business) back in 2003 (Annex B, Resolution 1378, 2003). Consequently, the number of organisations that were able to provide independent data on exposure to ionising radiation was reduced from dozens to very few research groups. The only independent research body that survived was the Institute of Radiation Safety BelRAD (established in 1990). However, its once ambitious research and awareness-raising programme has been refocused to measurements commissioned by third parties, and its biannual bulletin *Chernobyl Disaster*, which contained detailed overviews of its dosimetry work, was discontinued in 2007. The reason cited in the last issue was that the statistical sample was no longer representative due to the reduction of its monitoring network (Nesterenko, 2007). In 2003–2004, the government also started the "optimisation" of NGOs active in the field to make sure that they did not compromise the integrity of the new policy approach; most of them did not survive (interview nos. 5 and 6).

Chernobyl's science production in Belarus was and continues to be fuelled almost exclusively by the projects and programmes commissioned by the state. International funding is scarce and comes primarily through collaborative arrangements involving the government, such as the IAEA, UNDP, and the Union State of Belarus and Russia. The governmental funds are distributed by the Department for Liquidation of Disaster Consequences (and its predecessors). (See Fig. 2 for formal interactions between the research institutions and governmental agencies concerned with the Chernobyl aftermath.) The call for proposals is sent out annually, but funding is allocated to only a few privileged research groups. One interviewee gave an example of a senior researcher who wrote dozens of invariably successful project proposals when he worked at a "privileged" institute but became consistently unsuccessful when he changed his job (interview nos. 1).

3.2. How much radiation is too much?

Policy-makers need clear thresholds, and initially, in the USSR in 1988, the safe threshold for the committed effective dose of ionising radiation over a lifetime was established at 35 roentgen equivalent man (rem), which is equal to 350 mSv; this was proposed in 1988 by L. A. Il'in, the director of the Institute of Biophysics of the USSR Ministry of Public Health, and Y. A. Israel, the head of the USSR State Committee for Hydrometeorology (Yaroshinskaya, 2011). In April 1989, the Belarusian Soviet Socialist Republic (BSSR) Academy of Sciences submitted to the BSSR Government and Communist Party a report contesting the 35-rem dose and requiring a lower one (International Advisory Committee, 1992). The report was forwarded to the USSR government than responded by a communication on November 28, 1989, confirming the validity of the 35-rem dose (ibid.). Furthermore, the USSR Governmental Commission for the liquidation of the consequences of the Chernobyl accident approved the concept and ordered that it be used from 1990 onward (Yaroshinskaya, 2011).

To claim legitimacy through international recognition, the USSR government requested international organisations to evaluate its rehabilitation measures (including the validation of Il'in's and Israel's proposals) and outline suggestions for future policies. In response to this call, the IAEA launched the International Chernobyl Project in cooperation with WHO, International Red Cross (IRC), and the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). The project report (published in 1992) concluded that the liquidation and rehabilitation measures taken by the USSR government were sufficient and complied with the IRC's guidelines, and many measures were even recognised as excessive in terms of applicable IAEA standards. The findings also confirmed that the 35-rem threshold was overly conservative and was adopted as a result of strong political pressure rather than based on the best available knowledge (International Advisory Committee, 1992).

The political pressure resulted from the massive information and communication crisis that followed the Chernobyl disaster, as well as the low trust in the ability of public authorities to ensure the radiation safety of the population (Petryna, 2004; Yaroshinskaya, 1992). Ultimately, in the aftermath of Chernobyl, the failure to govern in a transparent and legitimate manner was among the major reasons for the collapse of the Communist Party and the disintegration of the USSR in 1991 (Stepanov, 2010). A comparison of this impact with that of post-Fukushima Japan is interesting. In the latter case, the information and communication crisis was similar in many ways (Yamane et al., 2013) but did not appear to have any sizeable effect on the political landscape,

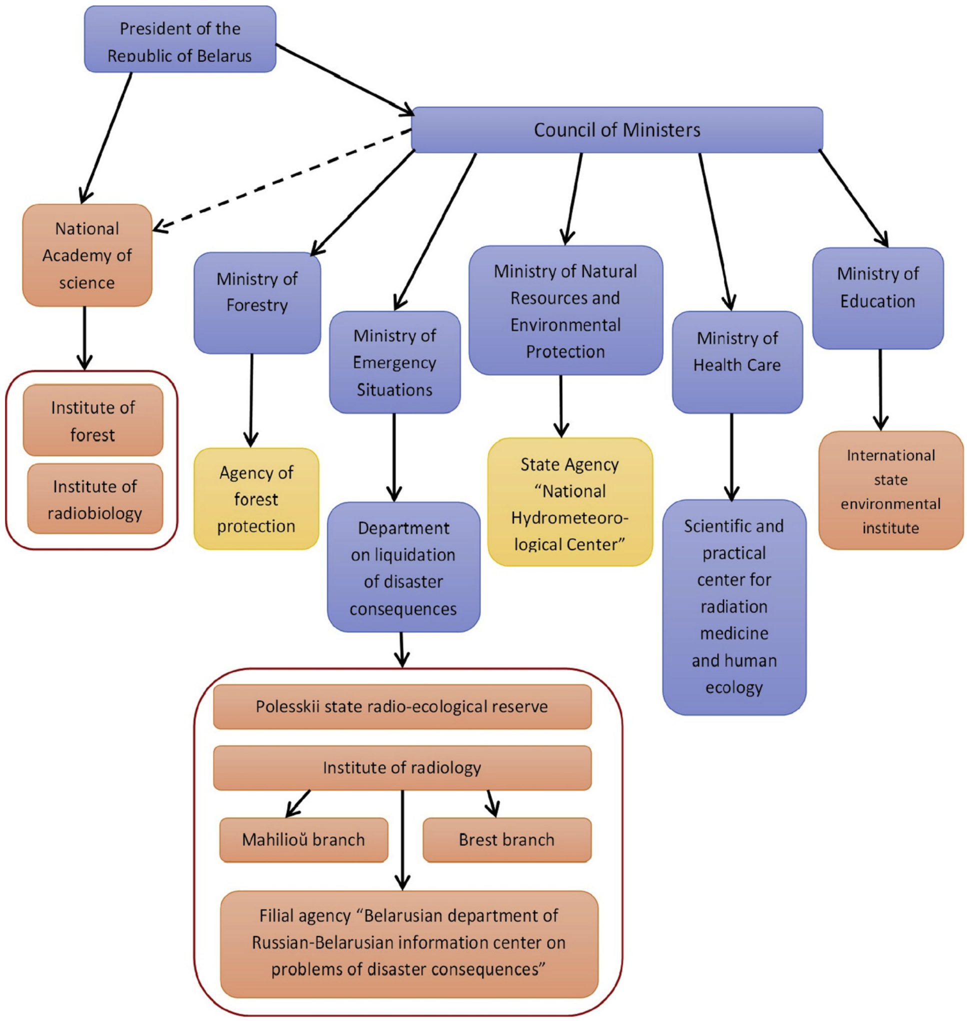

Fig. 1. State actors involved in Chernobyl science and Chernobyl policies as of 2016.

and the discussions on the post-disaster management approaches and safety standards did not become a political issue (Hamada et al., 2012).

In Belarus (then BSSR), the debates around the acceptable dose threshold were politically charged from the very beginning, as the emerging parliamentary opposition placed them at the core of its political agenda, and the government could not afford for the opposition to take control of the discussion (Stepanov, 2010). It is against this backdrop that the 7-rem threshold (as opposed to the USSR government-promoted 35 rem) was accepted by the BSSR parliament and signed into law (Annex B, Legal Status Law, 1991). The guiding assumption was that the threshold of the committed effective dose would be 1 mSv/y, with the average life expectancy of 70 years (making for a lifetime 70 mSv). The final decision was greatly influenced by an emotional speech given by the poet Ales' Adamovich, who argued that farmers were intimately engaged with their soil and that this caused much higher radioactive intakes than any estimates by Il'in and Israel (Adamovich, 1992). To compare, shortly after Fukushima, 1 mSv/y was the recommended threshold established by the Japanese radiation safety authorities for radiocesiums and transuranic α-emitters for the radiation intake associated with foodstuffs (Hamada et al., 2012); however, this represents only a portion (although a very significant one) of the total intake, and life expectancy is longer in Japan (i.e. Belarusian standards are still stricter).

The legislation establishing Chernobyl policies in Belarus in the early 1990s can, therefore, be considered an example of the precautionary principle application, but without labelling it this way. Stirling (2012) referred to such a state of knowledge as *ignorance*, describing it as a situation when the rationale behind the decisions was grounded in values rather than scientifically proven knowledge. This value-driven character is used as a point of departure by critics of the 35-rem and 7-rem approaches. For instance, Bolshov et al., 2001, working at the Nuclear Safety Institute (run by the Russian Academy of Sciences jointly with the Rosatom Russian State Atomic Energy Corporation), specifically blamed artists and men of letters for "aggravating the situation" and fuelling the public with emotional opinions. This resulted, they argued, in unprecedented and wasteful economic losses and even in public health issues, as being presumably wrongly identified as having been exposed to harmful levels of ionising radiation, people were under stress (ibid.). The way in which the argument was delivered by this influential research group was structurally similar to the claims of the Belarusian authorities who were arguing with Moscow authorities and promoting the 7-rem concept in 1989–1991 (backed by the BSSR Academy of Sciences). Both claimed their monopoly on "serviceable truth" (Jasanoff, 2003) through the appeal to "scientific knowledge", while they similarly overlooked the situation of ignorance (Stirling, 2012) and did not consider the scientific uncertainty in a consistent manner.

3.3. Are low levels of radiation low enough?

The internationally recognised concept of radiation safety is a *linear non-threshold (LNT) hypothesis* that was put forward by the International

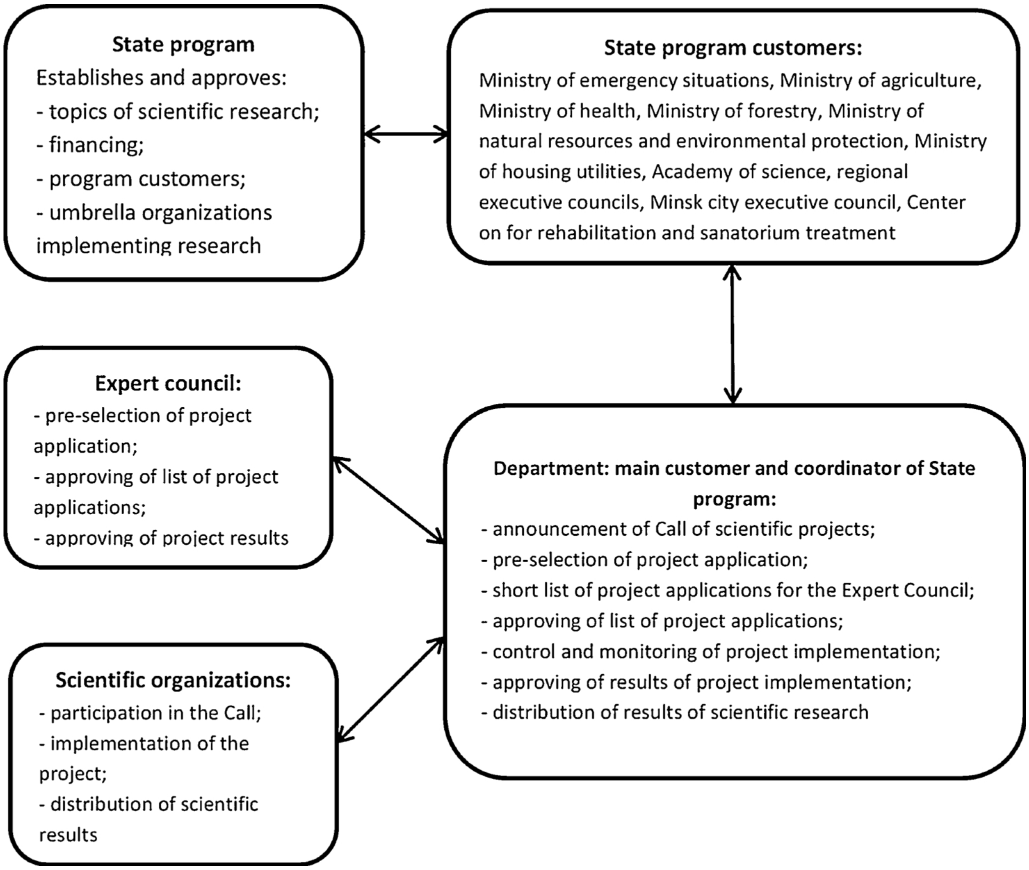

Fig. 2. Formal interactions between research institutions and governmental agencies concerned with the Chernobyl aftermath.

Commission on Radiological Protection (ICRP et al., 1977). It assumes that even long after actual exposure, and regardless of dose and intensity, ionising radiation may cause cancer. As ambiguous (in terms of policy-makers) as it gets, the LNT hypothesis has never been contested with more credible proposals, although the ICPR is looking for possibilities to establish a universal threshold dose below which there is no risk of radiation-related cancer (ICRP et al., 2005). However, the available evidence base is still all too uncertain, not least due to the difficulties with registering the actual effects of low doses of ionising radiation against the backdrop of the other environmental and non-environmental factors to which individuals are exposed (Ryabuhin, 2000; UNSCEAR, 2012). To address these issues, the Belarusian parliament adopted proposals to combine the 7-rem dose with zoning, whereby zones were allocated based on ecosystem pollution and the availability of environmentally safe agriculture (Annex B, Legal Status Law, 1991). Russian (1995) and Ukrainian (1991; zoning policy was abolished in 2014) legislation followed the same approach, albeit based on different thresholds. The main advantage of this approach is its relative simplicity as regards the allocation of areas with certain "recognised" levels of radiation; however, it also multiplied uncertainties by hiding complexity.

The zoning policy is administered through regularly updated lists of settlements that are allotted to one of the zones. These lists are approved by the government and are based on the data for soil pollution by Cs-137, Sr-90, and Pt-238/239/240, as well as the annual effective doses calculated according to the *Catalog of average annual effective doses of exposure to residents of settlements* (Annex B; BORBIC, 1992, 2009, 2015). The catalogue is developed by the Research Scientific and Practical Centre for Radioactive Medicine and Human Ecology (RSPCRMHE) and approved by the Ministry of Public Health. It is based on *Methodological Guidance* developed by the same centre and approved by the same ministry (Annex B; RSPCRMHE, 1991, 2003, 2014). Discrepancies between the values published in the catalogue and independent field measurements (using whole-body counters) are common. Usually, the lower ones are found in the catalogue, while the measured doses are higher (Jacob, 1996), although, in their publications, the authors of the catalogues assume that normally it should be the other way around (Vlasova and Skryabin, 2011). Our interviewees (interview nos. 1, 2, 4) insisted that the bias was intentionally introduced by the RSPCRMHE based on an informal request by the commissioning governmental agency. However, this can also be explained by high uncertainties—for example, related to the modelling approach used to calculate radiation intakes, scarce validating data, variability caused by individual lifestyles, and so on.

Alternative models of committed doses have never been proposed within the Belarusian scientific community, although the credibility of the BORBIC's Catalogues was seriously doubted by our interviewees (interview nos. 1, 2, 3, 4). Moreover, they were greatly concerned by the "ivory tower", if not plainly rude, attitudes of the lead authors of the catalogues, who refused to enter into open discussions about their findings (interview no. 2). Open discussion was also constrained by the fact that none but the latest revision of Methodological Guidance (RSPCRMHE, 2014) was accompanied by an openly available publication explaining the assumptions and mathematical foundations of the radiation intake model and containing information about the statistical sample used for modelling assumptions and validation (Vlasova, 2014). Nevertheless, this publication and any others explaining catalogues and guidelines (e.g. Vlasova, 2008; Vlasova and Skryabin, 2011) were not particularly helpful either, as they had only very generic descriptions of data and methods, no uncertainty assessments, and no clear explanations of how the sample was constructed. Moreover, the links to online databases seemed to be accessible solely from within the authors' workplaces, and the authors relied on numerous assumptions, generalisations, and correction coefficients to account for the factors that were not included in the core model. It is likely, though, that the poor quality of the publications was not intentional (i.e. to keep the methodology uncontested) but was rather due to the low overall publication standards of most research journals, including the prestigious ones, published within the former USSR.

The massive amount of evidence coming from the media and interviews suggests that to support the governmental agenda regarding the restoration of the Chernobyl areas, Chernobyl science was set to justify lower welfare compensation to the inhabitants of the contaminated areas (e.g. through establishing lower health risks compared to earlier standards [e.g. Cheshchevik et al., 2001] and recommending a broader range of economic activities as safe in terms of occupational health and the quality of products [e.g. Tsybylka, 2012]). For instance, in the areas with radioactive contamination from 1 to 5 Ku/km^2, governmental subsidies for rehabilitation measures and public health were cut and cash compensations to the local population abolished, while cash compensations in the areas with radioactive pollution above 5 Ku/km^2 were reduced (Annex B, Exchange of Documents Decree, 2009; Social Protection Law, 2009; State Program, 2010). Institutionally, this was also supported by a revision of the official list of ailments caused by radiation (i.e. two ailments directly caused by radiation and five implicitly related to it), while any other ailments were not recognised as related to Chernobyl radiation (Annex B, Resolution 73, 2009). In the original 1999 document (Annex B, Resolution 105, 1999), the list of ailments was more than two times longer than the one in the 2009 revision.

Compared to the recommendations of international organisations (e.g. the IAEA, ICRP, and UNSCEAR) and to the Japanese effective dose regulation standards adopted in the aftermath of the Fukushima accident (Mori et al., 2017), the thresholds and safety standards laid down in the new generation of Chernobyl policies were still very conservative. For example, the post-Fukushima threshold for the committed effective dose was 5 mSv/y, while the regulation values for radionuclides were substantially more relaxed for most foodstuffs (Hamada et al., 2012). It could be, therefore, that the radical revision of the Chernobyl policies were caused not only by shifting political priorities but also by the improved understanding of environmental factors and pathogenesis. At any rate, the truth is safely hidden under the veil of secrecy or by the restricted access to the high-resolution statistics that are monopolised by the state and the fragmentation of Chernobyl science, with its "privileged cluster" interfacing solely with dedicated governmental agencies. The latest development in the official Chernobyl science discussion is a proposal to abandon the zoning policy in favour of classifications of settlements based on exposure factors alone (Vlasova et al., 2016). This might be a sensible proposal, but likewise, it is not being discussed outside the privileged community and the government.

3.4. An overview of peer-reviewed research outcomes

A quick check on the Scopus and RINC[1] databases showed that Belarusian Chernobyl scientists were not particularly productive. Excluding short abstracts and posters, we found only 123 Scopus- and 316 RINC-indexed papers. RINC indexes most Belarusian, Russian, and Ukrainian journals and books that comply with the minimum reviewing requirements and are visible to colleagues from Russian-speaking scientific communities; it also covers some international periodicals. Most of the Scopus-indexed publications were submitted by large international teams of authors. Of these papers, 26.8% featured authors with all-Belarusian affiliations, and most of the publications were written in Russian. Of the Scopus-indexed papers, 88.6% dealt with topics such as health and radioactive pathology (41.5%), the migration of radionuclides in ecosystems and non-human species (17.9%), soil migration and crop protection (15.4%), and the character of pollution and dosimetry methodology (13.8%). Themes such as food safety were almost absent in the Scopus-indexed journals (0.8%) but were significantly present in the RINC-indexed ones (8.2%). For socioeconomic research and post-Chernobyl policies, the contrast was also significant (3.3% and 12.3%). Papers covering the estimation of the effective doses have never appeared in any Scopus-indexed journals, although this topic received a significant amount of coverage in the RINC-indexed ones (15.5%).

This bibliometric snapshot (and similar insights from other fields of environmental studies) shows that "hard science" studies backed by experimental data are significantly better represented in international peer-reviewed (Scopus-indexed) journals than those explaining Chernobyl policies and management approaches. There can be several explanations for this. One is that Scopus-indexed publications usually result from collaborations within international projects and networks, which are mostly concerned with measurement-based natural science research. Another is that such "hard science" is not regionally bound and has a broader potential readership than multidisciplinary management- and policy-related environmental and health studies focusing narrowly on Belarus, which were of interest solely to readers in Russia and Ukraine. In addition, because in most RINC-indexed papers—for example, those explaining the approach to the estimation of effective doses—data handling and methodology are poorly explained, they might have had little chance of surviving review in major international journals. (Our interviewees are aware of at least two submission attempts.)

4. Discussion and conclusion

Sheila Jasanoff (2003) argued that "modern institutions still operate with conceptual models that seek to separate science from values, and that emphasize prediction and control at the expense of reflection and social learning" (p. 243). Unusually, the history of Chernobyl policy and science in Belarus started with a short period in the early 1990s, when the values voiced by a broad range of stakeholder groups were prioritised over conclusive research and economic rationale. As a result, the parliament adopted adaptation and rehabilitation policies and legislation that adhered fully to the precautionary principle. Several years later, it was recognised that this precautionary action was not economically viable, and although the overall declared policy approach remained the same, it was greatly eroded by the modified institutional environment and by the implementation practices, which were branded as evidence-based and endorsed by international organisations.

In sum, Chernobyl knowledge production politics from the 1990s can be seen as a massive effort on the part of the Belarusian government towards the reduction of organisational diversity of the Chernobyl scientific community to eliminate concurrent knowledge production. In doing so, it channelled public funds to a limited number of selected research organisations affiliated with the governmental body in charge of Chernobyl affairs, removed non-state actors from Chernobyl research, and monopolised data collection. This "institutional monocropping" led to the establishment of a closed and hierarchically accountable expert community tasked with the production of grey literature (internally produced and reviewed and mostly not released to public) addressing the pending priorities and providing simple and straightforward (and more economical, as our evidence suggests) solutions. A cost-cutting agenda was pursued as well.

While it is not uncommon for governmental organisations to prefer grey literature (Suzuette, 2017), it was always an absolute preference for the Belarusian government (e.g. Shkaruba et al., 2015). To a certain extent, this is a way to make relevant scientific knowledge *accessible* and *applicable*, as interpreted by the ACTA framework (Dunn and Laing, 2017), or *relevant* and *legitimate*, as defined in CRELE (Sarkki et al., 2014): decision-makers are often confused about the difficult, overly theoretical language of research papers and about the vagueness of

[1] Russian abstracting system and electronic library, https://elibrary.ru

conclusions and their low relevance to pending policy questions or the real needs of stakeholders (even if the research questions seem to be perfectly relevant), the applicability of methods, and so on.

Indeed, robust "professional consultancy" science can, to some extent, answer all of these concerns. Furthermore, it addresses some of the SPIs' trade-offs identified within the CRELE framework (ibid.). For example, *interfacing* (competing for time with other activities) is a core part of the routine agenda of privileged institutions of Belarusian Chernobyl science, although it involves only selected governmental agencies and stakeholders. Quite a significant amount of hidden boundary work is occurring within them, and as such, it does not compromise other activities, while the research of these groups is clearly demand-driven and less dependent on supply options. In contrast, the *clarity–complexity* trade-offs (i.e. simple messages vs. communicating uncertainty) can be easily compromised in favour of simple messages: decision-makers often have a strong preference for simple messages, and as we demonstrated, in Belarus, they also receive them simple. In the *speed–quality* trade-off, preference is likely to be given to speed instead of in-depth quality assessments, as grey literature deliverables rarely get a proper review, and if they do, it is the same small, privileged circle of organisations which is eligible to supply reviewers. This means that quality assurance is not rigorous.

In the ACTA framework, decision-makers share concerns about the *comprehensiveness* of policy-relevant knowledge. Formally speaking, the grey literature addresses this: in Belarus, estimations of economic and financial impacts are compulsory for this kind of report, although the interviewees had their doubts that such estimations are taken seriously enough by all involved. Other components included in the ACTA framework's *comprehensiveness*, such as the inclusion of multidisciplinary perspectives or contextualisation (e.g. ranking risks and placing the recommended options in a comparative context), seem to be required by Chernobyl decision-makers as well (or, at least, are typically mentioned in terms of references). Judging from the contents of disclosed reports (e.g. on the options for effective doses) and the follow-up publications, these requirements were taken very lightly by researchers but, apparently, also by contracting governmental agencies. Peer review, if applied, does not fix this, as was also discussed in regard to the CRELE framework's *clarity–complexity* and *speed–quality* trade-offs. In terms of *credible* policy-relevant knowledge production, the governmental policy had a negative impact on the whole body of the Belarusian Chernobyl science community (including its "unprivileged" segment). It played a role in reinforcing contextual factors, such as weak internationalisation, small community size, and critical dependence on governmental policies and finance, and further compromised the credibility of Chernobyl science.

Our bibliometric study further demonstrates that even in traditional terms, the research supporting Belarusian Chernobyl policies is not properly reviewed. Research papers undergo only a very light review process in Belarusian and Russian periodicals, with their relaxed data presentation and methodology explanation requirements, while reports and policies pass internal reviews by governmental agencies and external reviews by intergovernmental organisations, such as the IAEA. Research and policy papers are not exposed to international scholarly peer review, and non-state stakeholder groups within the country are not consulted. With only some sorts of internal boundary arrangements taking place, the options for extended peer review (Funtowicz and Ravetz, 1992) are virtually nonexistent. Apparently, as far as international recognition is concerned, the *credibility* of Belarusian Chernobyl science is limited, at least when it is not measurement-based natural science. The recognition by Belarusian decision-makers is not very consistent. While constantly praising Chernobyl science outputs, they also continue to cut research funding.

Further reflecting on the bibliometrics, we can recognise the failure of international scholarly networks and the very institution of international peer review to support the strategic development of knowledge by science. Technically, the IAEA, UNSCEAR, and ICRP are the only reviewed sources of internationally accessible, scientifically based advice on policies and management in the aftermath of nuclear accidents. The papers written by Japanese scientists in the aftermath of the Fukishima disaster do add to the pool of internationally accessible literature; however, they build on experiences that are limited to only a few post-disaster years. Interestingly, they consistently omit references to the Belarusian (as well as Russian and Ukrainian) body of work—for example, that which explains the models developed for threshold committed effective doses. This situation can be defined as the "scientific advice oligopoly" of intergovernmental organisations.

Our discussion of the CRELE and ACTA frameworks suggests that ACTA needs a context in which decision-makers understand the benefits of comprehensive policy advice covering a variety of options and disclosing uncertainties. In the Belarusian PNS and top-down governance context, this understanding is often limited (if not blocked) by at least two issues. The first is that any comprehensive perspective on a highly complex unstructured problem would conflict with the ACTA requirements for knowledge accessibility. Furthermore, participatory-based solutions, such as extended peer review or "policy as learning" (Hisschemöller and Hoppe, 2001), do not work in top-down societies. The second is that in top-down societies, knowledge production also tends to be top-down. As we see in Belarus, it was a deliberate choice of decision-makers to consume research products supplied by the small, "privileged" Chernobyl research community, blindly trusting their quality and relevance, as long as these deliverables fit the agenda and were not contested by international organisations (both being feasible conditions). We therefore argue that in a PNS situation CRELE appears to be a more versatile framework for evaluating SPIs, as across different governance contexts its variables provide more consistent characteristics of the quality and relevance of knowledge, as well as its usability and acceptance.

Belarus is a relatively small country, and although it makes in-depth and highly specific studies manageable, this also places limits on the applicability of our conclusions and the validity of our assumptions. Larger research and stakeholder communities may have different dynamics and may result in different interfacing arrangements. For example, we can expect even relatively closed, "privileged" research communities to be able to perform well in terms of scientific peer review, if they are big enough. Likewise, size can be critical in terms of the quality of boundary arrangements that may potentially provide functional options for extended peer review, even in authoritarian societies. Research on science–policy interfacing in the aftermath of nuclear disasters in countries such as China or Russia would certainly help to shed more light on this problem.

Acknowledgement

This work was supported by the EU Erasmus + Program (Jean Monnet Modules) under grant 553575-EPP-1-2014-1-BY-EPPJMO-MODULE and from the institutional research funding IUT (IUT21-1) of the Estonian Ministry of Education and Research.

Appendix A

See Table A1.

Table A1
List of interviewees.

Interview, id	Interviewees	Description	Time of interview
1	Former head of scientific research laboratory at the Institute of radiology	A scientific supervisor of several major projects implemented under State programs for overcoming Chernobyl disaster consequences. He left laboratory due to budget cuts	March, 2016 September, 2016; December, 2016; June, 2017; October, 2017
2	Former staff of the scientific research group at the Institute of radiology	An expert involved in the radioactive monitoring of contaminated agricultural lands up to December, 2016 (when institute was stopped its activity)	March, 2016 April, 2016; September, 2016; December, 2016; June, 2017; October, 2017
3	Staff of laboratory for radioactive control of forest in Mahilioŭ Region	An expert involved in the radioactive control of forest products	June, 2017
4	Staff of laboratory of Mogilev regional office of the health and epidemiologic control	An expert involved in the control of radioactive elements in milk, forest berries and mushrooms	September, 2017; November, 2017
5	Retired staff of the Department for Liquidation of the of Chernobyl Aftermath	An officer at the State Department for Liquidation until his resignation in 2011	May, 2017 October, 2017
6	Former member of Belarusian Parliament, 1990-1995	A member of the parliamentary opposition	November 29, 2017

Appendix B. Key Chernobyl regulation, legislation and guidelines

Laws, 2018 Laws, decrees and resolutions

Exchange of Documents Decree, 2009 Exchange of Documents Decree, 2009. On some issues of the exchange of documents confirming the right of citizens to privileges. Decree of President of Republic of Belarus No 407., approved 04.08.2009.

Legal Status Law, 1991 Legal Status Law, 1991. On the Legal Status of the Areas Exposed to the Radioactive Pollution Caused by the Chernobyl Disaster Law. Vedamastsi Vyarkhoŭnaga Saveta Respubliki Belarus, № 35, art. 622 (law was revised in 1999, in 2006, in 2010, in 2012, in 2016).

Social Protection Law, 2009 Social Protection Law, 2009. On the social protection of citizens affected by the Chernobyl disaster, other radiation accidents Law. National Registry of Legislation Acts, № 17, 2/1561.

Resolution No 73, 2009 Resolution No 73, 2009. On the approval of the list of diseases, the occurrence of which is associated with direct radiation exposure, the list of diseases that may arise from the Chernobyl disaster, other radiation accidents, approved by Ministry of Health 26.06.2009.

Resolution No 105 and resolution No 105, 1999 Resolution No 105, 1999. On the approval of lists of diseases, the occurrence of which may be due to the consequences of the Chernobyl disaster, approved by Ministry of Health 06.04.1999, resolution No 105.

Resolution, 1378 Resolution 1378, 2003. On approval of provisions on licensing of types of activities, the issuance of licenses for which is carried out by the Ministry of Health, approved by Council of Ministers of Republic of Belarus 20.10.2003, No 1378.

Policies and guidelines

State program for overcoming the consequences of the Chernobyl disaster for 2011–2015, 2010 State program for overcoming the consequences of the Chernobyl disaster for 2011–2015, 2010. Approved by Council of Ministers of Belarus from 31.12.2010, No 1922.Rules, guidelines, standards. BORBIC and BORBIC, 2015 BORBIC, 2015. Catalog of average annual effective doses of exposure to residents of settlements of the Republic of Belarus. BORBIC, Gomel, 73 p.

BORBIC and BORBIC, 2009 BORBIC, 2009. Catalog of average annual effective doses of exposure to residents of settlements of the Republic of Belarus. BORBIC, Gomel, 86 p.

BORBIC, 1992 BORBIC, 1992. Catalog of radiation doses of residents of settlements of the Republic of Belarus. Approved by Ministry of Health of Republic of Belarus in 1992.

RSPCRMHE, 1991 RSPCRMHE, 1991. Methodological Guidance. Estimation of annual total effective equivalent doses of population for controlled areas of the RSFSR, USSR, BSSR, exposed to radioactive contamination as a result of the Chernobyl nuclear power plant accident. Approved by chief sanitary officer of USSR 05.07.1991, № 5792-91.

RSPCRMHE, 2003 RSPCRMHE, 2003. Methodological Guidance. Estimation of the effective dose of external and internal exposure to persons who live in a territory that has been exposed to radioactive contamination as a result of the Chernobyl catastrophe, approved by Ministry of health, Minsk, 2003.

RSPCRMHE, 2014 RSPCRMHE, 2014. Methodological Guidance. Method for estimating the average annual effective dose of exposure to residents of populated areas located in a territory contaminated with radionuclides as a result of the Chernobyl nuclear power plant accident, approved by Ministry of Health, Minsk, 2014.

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