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Yuliya Pranuza

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Capacity to build Artificial Intelligence Systems for Nuclear Energy Security and Sustainability: Experience of Belarus

Yuliya Pranuza ^[0000-0002-8803-6942]

Francisk Skorina Gomel State University, Gomel, Belarus
upronuzo@gmail.com

Abstract. In recent decades the danger of man-made hazards in the nuclear field has increased dramatically. Belarusian scientists have accumulated considerable innovative potential in health care, agriculture, the creation of new life support technologies in radioactively contaminated areas. This information is required when working out catastrophe scenarios at nuclear power plants. The definition of situational innovations is developed that are intended for use in certain circumstances and are essential for the achievement of unique goals including ensuring people's life and safety. The highlighting situational innovations makes it possible to determine their adaptation, use and replication in other economies, to diffuse them, to increase effectiveness of the cost of their working out. The results of the study indicate that (1) the unique experience of Belarus in overcoming the consequences of a nuclear disaster is of great practical importance for other countries operating nuclear objects, (2) the situational innovations resulting from the overcoming of nuclear disaster need to be consolidated into a data base and incorporated into the international data base of the results of nuclear research, (3) the application of Artificial Intelligence (AI) systems allows to accumulate, store, speed up the search of information in a single source and provide the necessary situational innovations in case of need (nuclear accident). AI systems also help to prevent and reduce the risk of nuclear accidents. Development and using AI will allow to help countries worldwide develop nuclear disaster information management systems and reduce existing disaster risk for sustainable development in the future.

Keywords: Nuclear disasters, Situational innovations, Data base, Artificial Intelligence, Knowledge Management.

1 Introduction

The economic success of the developed countries of the world is determined by innovation but innovation is not always good.

Human activities have become a real factor of the global negative impact on nature. Environmental pollution has become a worldwide damage. Vast territories, oceans and

people suffer from the harmful emissions of industry. Different kinds of animals, insects, plants are disappearing. Often these processes become irreversible.

Innovation creates new risks and may increase the probability of accidents, catastrophes, and poorly predicted events. Catastrophes at nuclear plants are a good example of it. Nuclear disasters have a particular negative impact on the sustainability of the ecological ecosystem.

Unfortunately, the world knows examples of such major accidents which have caused great environmental damages and are an obstacle for sustainable development: Three Mile Island (1979), Chernobyl (1986), Fukushima Daiichi (2011). These accidents have caused great environmental damages and are the obstacle for sustainable development. "These serious accidents produce human, material losses and pollution that cannot be recovered" [1].

The aim of this article is to justify the necessity to use the possibilities of AI systems for the distributing in other economic systems the unique experience of Belarus in obtaining situational innovations that are of great importance for people's health worldwide.

As a result of the disaster at the Chernobyl nuclear power plant the economy of Belarus has suffered in considerable damages. Belarus was exposed to significant radioactive contamination after the disaster. Today, 35 years after the accident, one of the reasons of the low level of social economic development is the consequences of the nuclear disaster.

Many problems had to be solved for the first time and in a very short period of time under conditions of high radiation. Due to specific limited demand, a large number of innovations have emerged. This work is still under way. It was suggested that such innovations be allocated as a separate group - situational innovations.

Situational innovations are innovations that have been applied under certain unique circumstances that are needed in the course of the implementation of poorly studied events, and that have the potential of using in other socio-economical systems [2].

Innovations generated within certain industries (especially those with the potential for adverse events) should be available for application in relevant organizations around the world.

The need for such information is demonstrated by the considerable increase in mutual contacts between Belarusian and Japanese scientists working on the problem of reducing the effects of radiation by the results of the large disaster at Fukushima Daiichi (2011).

The analysis of feedback from such catastrophes and incidents helps improving design, maintenance and training, planet protection, security and decision about the next purchase, but cannot repair damages. It is insufficient for preventing the next disaster, because the knowledge of context is incomplete [1]. But the accumulated information certainly helps to reduce uncertainty and risk of repetition of negative events in the future in the field of nuclear plants.

The present article tries to clarify possibilities of AI systems to create, store, search for and ultimately reduce the existing nuclear disaster risk for sustainable development.

2 Experience of Belarus

The territory of Belarus was exposed to significant radioactive contamination after the Chernobyl (Ukraine) nuclear power plant disaster. The release of a large number of radionuclides has altered the natural environment in large areas.

The disaster caused the death and illness of many people, irradiation of various severity and the contamination of vast territories of Belarus, Ukraine, Russia and other countries.

As a result of the initial explosion at the Chernobyl nuclear power plant (1986) and subsequent fire after it the radionuclides were transferred from Chernobyl in Ukraine across the border to Belarus what resulted in the contamination of 47,600 square kilometres (23 percent of the territory of the country on which 20 percent of its population lived [3]. Some 21 percent of the country's agricultural land, 23 percent of the forested land and 132 mineral deposits were polluted [4].

The negative impact for infrastructure and the relocation of people from polluted regions have become the reason of decrease of economic activity. The tasks of minimizing the consequences, as well as creating a safe living environment after the disaster, could not be solved on the basis of the available possibilities at that time. Innovative solutions were needed.

Specific problems that have arisen since the Chernobyl disaster (1986):

- i) the high risk of the consequences of the catastrophe especially for the population and the need to take unique decisions in a short period of time,
- ii) difficulties in assessing the effects of radionuclides on humans and the natural environment,
- iii) lack of reliable means of identification, measurement and evaluation of adverse effects and radiation,
- iv) lack of knowledge and practice of minimizing the consequences of a major nuclear accident,
- v) application of unique technical solutions adopted in the course of post-disaster operations and constantly adaptable to specific situations,
- vi) training and professional retraining of a large number of specialists in the application of various types of technologies not previously used or described in the literature,
- vii) high level of fatal risks for the participants in the disaster,
- viii) some erroneous management decisions based on ignorance of the conditions of the situation, etc.

The practice of unprecedented and effective interaction of the main components of the innovation process (scientists and practitioners introducing new ideas have emerged). The Chernobyl problems were new for that time and required a change in scientific thinking and action even for the most authoritative scientists.

Much has been done by trial and error and usually without experimental checkup. Decisions have been taken in high risk situations. Perhaps for the first time large-scale innovations were introduced in a highly uncertain and dynamic environment.

In Belarus, specialized research institutes have been established in a short period of time. The medical centers have been built to treat the affected inhabitants from radiation exposure. The recommendations have been prepared on the maintaining of production and the prevention of diseases, radiation monitoring, etc. Wherein, the rules of living

have changed. Large areas have been made uninhabitable and potentially dangerous for long-term visits.

New habitation patterns have emerged: limited use of local raw materials; the need for a reprofiling of production; changing demographics, etc.

For the territories affected by the disaster, there were specific needs that were not present on other territories, namely:

- i) radiation-safe living conditions,
- ii) 'pure' food,
- iii) special medical care,
- iv) improvement of the 'clean' areas with regard to radiation,
- v) compensation for damage and risk of living in contaminated areas,
- vi) special information services,
- vii) relocation to 'clean' land,
- viii) additional measures to support the development of the economy, etc.

In the Belarusian part of the exclusion of the Chernobyl zone nuclear power plant on the territory of Gomel region (Braginsky, Narovlyansky and Khoyniki region) the Polesie State Radiation and Ecological Reserve was organized (1988) [5]. The population living on this territory was evacuated and the land was taken out of economic use. The total area of the reserve is over 217,000 hectares.

The reserve was established with the aim 'of implementing measures to prevent the removal of radionuclides outside its territory, to study the state of natural vegetation complexes, fauna, to conduct radiation-ecological monitoring, and to conduct radiobiological research' [5].

The Reserve monitors and controls the status of radionuclide contaminated territory. The processes of accumulation and migration of radionuclides (^{137}Cs , ^{90}Sr , ^{241}Am) in components of terrestrial and aquatic ecosystems are studied. The forecast of radiation situation in the closest to the Chernobyl nuclear power plant zone is being projected for a more remote period.

The reserve is the experimental base where research on agricultural activity in the conditions of radioactively contaminated areas is being carried out.

Scientific work in the reserve is important for biodiversity conservation. Fauna is developed in the absence of an anthropogenic pressure. For example, the acquisition of the reserve by the bison takes place naturally without human intervention. The permanent inhabitants of the reserve are bears, deer, wolves, lynxes.

The state of vegetation communities affected by radioactive contamination is being studied in the reserve. Factors influencing radionuclide accumulation patterns in different plant species are analyzed (based on plant characteristics and soil moisture availability).

The investigation of the impact of cesium and strontium contamination on plants in the environment is carried out. Within the framework of this work the possibility of obtaining pure production of beekeeping with the soil contamination by ^{137}Cs and ^{90}Sr has been confirmed. Plants that contribute to the production of low-radionuclide honey were identified.

Consequently, Polesie State Radiation and Ecological Reserve is a unique research object that conducts research and innovates numerous safety measures in a radionuclide contaminated area.

There are also other scientific organizations based in Belarus that have important scientific results in the nuclear field.

Such organizations include Institute of Radiobiology of the National Academy of Sciences of Belarus (Gomel), National Centre for Radiation Medicine and Man's Ecology (Gomel), Scientific and Practical Center of the National Academy of Sciences of Belarus for Bioresources (Minsk), etc [6-8].

For example, it was developed the contamination prediction model of cesium-137 and strontium-90 concentrations in crop production in the long term after Chernobyl nuclear accident [9]. The soil-to-plant transfer of radionuclides strongly depends on agrochemical characteristics of soils. The model offers a set of changeable soil parameters (acidity, humus content, exchangeable potassium and phosphorus) to make a more accurate prediction of ^{137}Cs and ^{90}Sr contamination for a selected variety. This prediction model allows to predict the accumulation the ^{137}Cs and ^{90}Sr in agricultural crops grown on contaminated soils of different types (on soddy-podzolic and peaty soils) in the long term after the Chernobyl accident.

It was developed the web application specifically designed for the calculation of prediction values of ^{137}Cs and ^{90}Sr concentrations for a wide range of crops cultivated on soddy-podzolic and peaty soils. The prediction model app is available in Russian only (<http://forecastmodel.pythonanywhere.com/>).

It was developed the agricultural recommendations for radiation-affected farmlands by the belarusian scientist. For example, the Recommendations on the application of mineral fertilizers for the perennial mid-season grass mixture cultivation on ^{137}Cs -contaminated peaty soils. And, the Recommendations for home crop cultivation and personal livestock farming in contaminated rural areas in the long term after the Chernobyl accident [10].

The innovations were created in Belarus which are needed in the situations of manage the nuclear accident and prediction the development the situation. These innovations have been tested in real situations of radiation.

The results of the research carried out by belarusian scientist and organizations should be applicable in other countries as they relate to life and health.

Consequently, Belarus had acquired unique experience and proposed innovative way of managing disasters. These innovations are extremely rare and are essential for achieving unique goals, including the lives and safety of people, the environment and animals.

Most importantly, these innovations are of important for people's lives and health. These innovations should be considered as situational innovations.

3 The Situational Innovations

Situational innovations are driven by a specific limited demand in the conditions of unique challenges.

The situational innovations have the potential for further application in other contexts and socio-economic systems [2]. Wherein situation is 'all the circumstances and things that are happening at a particular time and in a particular place' [11].

The situational innovations in the result are unique. Uniqueness can be defined as follows: 'Being the only one of its kind; unlike anything else' [12].

Situational innovations are not applied under normal conditions. There should be certain characteristics that are appropriate to the types of situational innovation that justify their use and their adaptation (if necessary). These include natural disasters (earthquakes, floods, tsunamis, pandemics), space and Arctic exploration, and other unique projects (the Large Hadron Collider).

The following features of situational innovation have been identified:

- i) the need for working out a response for solving unique problems in the absence of knowledge,
- ii) relatively low demand under special conditions (catastrophe),
- iii) the need to solve the problems in the shortest possible time,
- iv) the possibility to adapt and reserve further use in other economic systems and situations,
- v) financing, as a rule, with the participation of the state.

Situational innovations can be applied to disaster management in other countries, both commercially and non-profitably.

In the first case, Belarus can commercialize the results of its research in this areas.

In the second case, the results can be provided free of charge (as in the case after the accident on Fukushima Daiichi when scientific contacts between Belarusian and Japanese scientists have increased significantly).

Situational innovation can be commercialized when linked to tools of disaster management.

At the same time, in case of increasing importance of such knowledge (elimination of current accidents) situational innovation can be provided free of charge.

There is a scientific interest in classification of situational innovations due to their importance.

Situational innovations can be used within one organization or a group of organizations, only in certain industries or regions, in certain countries, or be in common use in organizations around the world (based on their possible scale of use). This approach highlights the innovations of level 1, 2, 3 and 4 (table 1).

Table 1. Classification of situational innovations according to possible scale of use (unique situation)

Level of using innovations	Scale of using innovations	Examples
Level 1	in single organizations	innovations are required in one or more organizations (use of the Large Hadron Collider and thermonuclear fusion plants)
Level 2	in selected countries	Arctic development, space exploration
Level 3	only in a single industry/region	nuclear energy, space exploration, radiation pollution and poisoning of territories
Level 4	in demand worldwide	Emergency and other monitoring systems, pandemic (Covid vaccination)

As an example of level 1 innovation (table 1) the Large Hadron Collider should be called which is the largest and only experimental facility in the world to study the results of the acceleration of protons, heavy ions (lead ions) and the products of their co-

bumping. This construction is unique in its kind so the innovations of the scientific experiment are assigned to level 1 innovation (table 1).

Specific innovations applied to specific climatic conditions and only by selected countries have been developed for the development of the Arctic (level 2 table 1). Competition for the wealth of the Arctic is tough enough, and the necessary information can be only provided on a cost-recovery basis.

It is generally accepted that the most dangerous objects created by mankind are atomic objects.

Unfortunately, the practice proved that they are not completely safe. There have been major nuclear reactor accidents around the world.

Therefore, the innovations generated in certain industries (especially those with the potential for negative phenomena) should be able to be applied in relevant organizations around the world (level 3 table 1). If the Japanese Government had had the information concerning the Chernobyl accident study the consequences of the technological disaster of Fukushima Daiichi would have been lower.

The global response to atomic catastrophes has generated a significant amount of innovations which are now dispersed in different countries and organizations. It is suggested to form a data base of situational innovations obtained in the process of the implementation of measures to minimize the consequences of atomic catastrophes on the basis of an international organization (United Nations Office for Disaster Risk Reduction).

Level 4 innovations (table 1) include innovations used in many countries around the world. These can be technological (product and process), organizational, and environmental innovations that, because of their specifics, can be applied by a wide range of organizations. Examples include an emergency monitoring system (floods, earthquakes) and a vaccine that every person on the planet is entitled to receive during a pandemic.

Situational innovations have the potential to be adapted and applied in a similar way to the initial unforeseen (unplanned) situation that gave rise to them. Accordingly, it is advisable for certain unique situations to draw up a list of characteristics that define and characterize specific situations.

Based on the results of a specific unique situation, it is necessary to establish a list of innovations, the use and adaptation of which will be appropriate in future.

This can be demonstrated by the Chernobyl disaster.

Table 2 contains a list of characteristics that define the situation at the beginning of its implementation.

Table 2. List of situational characteristics and directions of innovation (situation is the disaster at a nuclear power plant)

List of characteristics	Directions of innovation
Changing environmental characteristics (radiation pollution)	Medical aspects of life in the territory of radioactive contamination
Human radiation exposure	Production of suitable agricultural products (protective measures)
Need for special protective measures	Animal husbandry in the face of radioactive contamination
Biomedical restrictions on economic activities	Activities in exclusion and eviction zones (decontamination works)

Evacuation of the population from the disaster epicenter	Ensuring safe living conditions in areas of radioactive contamination
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It also identifies areas of innovation which can be adapted and applied to a situation with similar basic determinants. Other situational innovations may also receive similar systematization.

4 Artificial Intelligence Systems for Nuclear Energy Security

Nuclear disaster risk can be facilitated by the use of AI systems. These systems make it possible to control and manage nuclear power plants safety, improve forecasting and establishing support system for radiation accidents, create nuclear knowledge management system, develop science, create robotics technology. Consider the directions of the AI in detail.

4.1 Safety Control and Managing Nuclear Power Plants

AI systems can be applied for nuclear power plants surveillance and diagnosis of problems on nuclear power plants.

AI allows to perform fast analysis of data coming from special cameras in real time based on the technology of computer vision and analysis of video images AI permits to compare them with reference data of the information database and to determine the presence or absence of a problem (for example, defects in reactor).

AI also calls for the creation of digital duplicate of nuclear power stations. Such 'digital doppelgangers' accumulate data from sensors installed on a nuclear reactor and allow to create digital copies of the entire nuclear device process.

Consequently, AI systems is a basic technology for controlling safety nuclear power plants which minimizes human factors and ultimately improves the safety and security of the nuclear power plant.

4.2 Improving the Forecasting and Decision-making Support System for Radiation Accidents

The AI allows considering a large number of factors that have preceded or accompanied accidents in the past.

AI allows to analyze disaster impacts taking into account a large range of socio-economical aspects based on the analysis of this information and the results of monitoring of current situation.

AI provides an opportunity to simulate the spread of the radioactive cloud after the accident at the nuclear power plant, to develop an algorithm of accident prevention, to predict risk of disaster and to offer early warning.

AI can be used to improve existing decision-making support system for radiation accidents. For example, such as the system RODOS (Real time On-line Decision Support System). This system is applied for off-site emergency management after nuclear accidents for more than ten years in European and Asian countries [13].

4.3 Nuclear Knowledge Management

The nuclear industry is knowledge-based and depends on the exchange of information and experience in the design, construction, operation and decommissioning of nuclear objects.

AI is a tool for managing a great amount of nuclear data, information and knowledge.

AI systems improve the organization of data and information by linking different sources together. In this case they can be mutually shared and reused in different countries among many organizations of different types.

The results of previous research may become more accessible to stakeholders in different countries and are based on the development of distributed knowledge bases. This is really important in the context of Open Science.

Over the past decades experiences have demonstrated that knowledge management powered with AI bring considerable help in decision making related to risks prevention and management in the nuclear areas. It is vital to prevent efficiently such accidents using all available information.

To avoid human and others loss it becomes necessary to learn how to recognise and evaluate the early warning signs, gather all available knowledge in aim to reduce loss and prevent risks (when it is possible).

As an example, the International Nuclear Information System (INIS) can be given [14]. INIS is a unique information resource that provides access to nuclear information from all around the world. INIS maintains one of the world's largest collections of publications on peaceful use of nuclear science.

4.4 Development of Science

AI is dedicated to improving the system of Nuclear Knowledge Management. The use of AI system is important for the processing data of scientific experiments taking into consideration numerous data already accumulated in the past.

AI can also be applied to calculation of physical processes and can accelerate calculation of changes in physical performance of a reactor.

The AI system brings together knowledge, helps make new discoveries and reduce the overall cost of R&D.

Nuclear safety research and development will become easier and faster and may lead to new scientific breakthrough and new knowledge in this field.

4.5 Robotics Technology

AI enables to develop robotic systems which explore and manipulate objects in extreme environment such as nuclear industry.

Robotics technology can be used in the entire nuclear cycle: operating reactors, building new reactors, decommissioning and waste storage.

The robots may be involved in dangerous or inaccessible locations (for example, dismantling reactors of failed nuclear plants or working with radioactive substances).

Cleaning up radioactive waste is a dangerous job for humans. In this case, robots for nuclear power plants are just irreplaceable.

The robots make it possible to study the level of radiation in places where the molten fuel is located.

Developing robots for solving critical nuclear issues is being actively developed nowadays.

For example, there is Department of Electrical and Electronic Engineering in the University of Manchester. The laboratory of Robotics for extreme environments has developed robots for nuclear power stations adapted to the conditions of the nuclear power plant in Japan [15].

AI can find other applications in nuclear power that we can only have a guess about today.

Finally, AI systems can take over the functions of station operator and all that is left for a man is the role of observer. Eventually, this will improve the reliability and safety of operating nuclear power plants.

5 Conclusion

Belarus was exposed to radioactive contamination after the Chernobyl disaster. Many problems had to be solved for the first time and in an extremely short period of time in conditions of high radiation.

Thanks to specific limited demand, a large number of innovations have emerged. Thus, a group of innovations was created in Belarus which are urgently needed in specific situations. Many of these innovations have been tested in real situations of radiation contamination and are of global importance.

The article justifies the necessity of allocating situational innovations into a separate classification group.

The use of situational innovations depends on the purpose, the critical period of application, the need to adapt to new developments, the need for special scientific support, limited use, lack of precedents in specific cases, etc.

The allocation of situational innovations allows to determine the directions of their adaptation and replication in other economic systems, ensure their diffusion, solve unique problems in a short period of time.

Belarus has accumulated unique experience in dealing with the severe consequences of the nuclear catastrophe. The acquired knowledge and experience are relevant and can be replicated in other regions.

The relevance of the suggested proposal was also confirmed by international experts. For example, in the OECD's review of Belarus «Innovations for Sustainable Development» it is noted: 'Domestic companies have acquired unique experience as, for example, in measuring radiation after the Chernobyl accident' [3].

Limited fuel and energy resources as well as the extremely high energy intensity of the economy were important prerequisites for the construction of a nuclear power plant on the territory of Belarus. The operation of any nuclear power plant has the potential of having an impact on the environment. In connection with the introduction of the Belarusian nuclear power plant (2020), there is an awareness of the need to expand radiation monitoring, contingency plans and the implementation of all recommendations of the International Atomic Energy Agency (IAEA) to ensure the necessary safety measures.

By creating a digital data base based on AI, it is possible to provide access to such innovations for international organizations. This will make it possible to quickly obtain the necessary information from a single source in case of need (especially in critical situations).

The innovations were created in Belarus can be apply in international cooperation of nuclear power. For example, The World Association of Nuclear Operators (WANO) is a particularly means of international assistance. These assistances include establishment of a worldwide integrated event response strategy. WANO membership involves all of the world's nuclear power plant operators and other organisations involved with nuclear safety. WANO's peer reviews represented a shift from just accident prevention to mitigation [16]. The IAEA Global Nuclear Safety and Security Network is allowing its members to share nuclear safety and security knowledge and services to further the goal of achieving worldwide implementation of nuclear safety and security [17].

The availability of information in case of nuclear disasters will help prepare for new emerging hazards and risks.

The proposal is of important practical significance for sustainability around the world taking into account current trends in the construction of small nuclear power plants and the production of small nuclear weapons.

The article also explains the need to use AI systems for managing nuclear power plants.

AI enables storing information about all processes of a nuclear plant and control them in real time, ensuring safe operation of a nuclear power plant.

The prevention and management of risks of a nuclear power plant require understanding of all facets and the choice of right decision.

Prediction using AI enables anticipation of potential problems and control of risks. It is necessary unpredicted risks such as nuclear plant accident is managed.

Decision making process in the nuclear field has to consider all risks that apply in a given situation (especially in critical situations).

AI will facilitate their collection for preservation, sharing, and reusing for a variety of applications.

'While there should not be elimination of human from the decision making process. Several accidents and disasters with fully automated systems demonstrated that the cognitive capacity of humans is necessary for now' [1]. In this situation AI is needed. The final decision should do human.

We have necessity of implementing the synergy of combining of human and computer capacities (AI) from the decision making process in the nuclear sphere.

Using AI the nuclear areas может быть положено в развитие Early Warning System Concept [18].

This concept facilitates the use of scenarios to show how and by which methods unforeseen and undesirable developments can be identified early. This approach allows the understanding of the likely origins of the undesirable developments, allowing rapid intervention.

Early warning and planning systems are an important for the early detection of undesirable developments or sudden and devastating events.

'Regardless of the area of use, an early warning and planning system is generally a combination of four elements: human intelligence, supporting analytical tools, planning scenarios and a monitoring mechanism clean' [18].

Using AI will allow to help countries worldwide develop nuclear disaster information management systems and reduce existing disaster risks for sustainable development in the future.

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