

Problems of solving the issues of nuclear facilities in Serbia - Spatial and planning aspect

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Abstract

The spatial planning is one of the key instruments for the planned formation and development of locations for nuclear facilities, especially in terms of meeting the strict spatial conditionality, as well as in terms of the formation of protection zones in their surroundings. This paper systemizes the international criteria and requirements for locations of nuclear facilities. The research was conducted on the example of the location of the Vinča Institute of Nuclear Sciences and proves the starting hypothesis that the general requirements related to the spatial development of locations of nuclear facilities and to the protection from radiation have not been met at the Vinča location and its surroundings. The radioactive waste has been stored at the Vinča location, which is not suitable for this purpose. The need to conduct the research that will define the potential zones for radioactive waste disposal is the basic starting point in this paper. The framework of the research is the development of *the Spatial Plan of the Republic of Serbia from 2021 to 2035*, on the basis of which it is possible to determine the potential zones for the construction of a radioactive waste repository. In this paper, the authors present the results of research on spatial constraints from the aspects of geological and hydrological conditions, spatial protection, distribution of the population, settlements and buildings, etc. A special contribution it makes is the additional analysis of conditionality in relation to the planned purposes and activities of national and priority importance in Serbia. The collection, processing, and presentation of spatial data is the result of analyses conducted with the support of the geographic information systems. The research contributes to a definition of the potential zones, within the scope of which it is necessary to conduct further research and select the optimal location for a radioactive waste repository. The paper also gives the recommendations for further spatial development and protection of the Vinča location and its surroundings. The paper provides the methodological guidelines for further scientific research into the spatial aspects of nuclear facilities in Serbia, at the same time pointing out the possible directions for further resolution of this issue in practice.

Key words: nuclear facility, radioactive waste, repository, spatial plan, location, constraints, protection, analysis, spatial data

1. Introduction

In recent years, spatial and urban planning has placed an increasing emphasis on the issues of environmental protection and assessing the impact of planning solutions on the future environmental quality [1]. In that sense, nuclear plants have a special weight in planning, both because of certain conditions necessary for determining their location, design, construction, commissioning, operation, closure, and decommissioning, and because of the impact they have, or can have, on the environment [2].

Most nuclear plants in Serbia are situated at the Vinča location, which covers the entire area of the former Vinča Institute of Nuclear Sciences, with an area of 48 ha near Belgrade, today divided into the Institute zone and the zone under the jurisdiction of the public company Nuclear Facilities of Serbia. *The Law on Radiation and Nuclear Safety and Security* [3] defines a nuclear plant as a facility, plant, or several functionally connected plants located on the same site and operated by the same person, being a plant for the processing or enrichment of nuclear material, a plant for the

production of nuclear fuel for a research nuclear reactor, a research nuclear reactor, a plant for managing used nuclear fuel from a research nuclear reactor, and/or a plant for managing radioactive waste. Radioactive waste is understood as radioactive material in a gaseous, liquid or solid state whose further use is not planned or foreseen [4], *i.e.*, material that contains or is contaminated with radioisotopes with activity levels higher than the limit levels determined by regulations, and which is not planned for further use [5, 6].

At the Vinča site, there are nuclear facilities of great importance in terms of their environmental impact and the implementation of the necessary measures of protection [7, 8], which, in addition to the research reactors RA, which has permanently ceased its operation, and RB, which is currently out of operation, also include the storage facilities for low and intermediate level radioactive waste and spent radiation sources. This waste originates from the previous activities of the reactors and other sources, such as the research activities at the Institute, *etc.* It consists of three hangars in which the waste is mostly in barrels, but it is also present in various bulky forms that could not be adequately processed and packed at the time of collection. The liquid radioactive waste is located in four underground reservoirs.

The Law on Planning and Construction [9] determines the long-term basis for the organization, arrangement, use, and protection of the space of the Republic of Serbia, and it is one of the development planning documents with which all public policy documents must be harmonized [10]. The spatial plan is further elaborated through a system of spatial and urban plans, from which, for the purposes of planning activities of national interest, the spatial plans for special purpose areas are developed.

In practice so far, two spatial plans of the Republic of Serbia have been developed and implemented. The first, in 1996 [11], defined the obligation for preparing a plan for the special purpose area of the Vinča nuclear complex and raised the open question of resolving the issue of finding a location for disposing of radioactive waste [12], and the second, from 2010 [13], did not mention this theme at all. *The Spatial Plan from 2021 to 2035* is currently being prepared [14], which the authors are using as a research framework, and in this study, they determine the potential zones for constructing a repository for radioactive waste in Serbia.

The basic hypothesis and starting point are that the general requirements related to the spatial development of nuclear facilities and protection from radiation at the Vinča location and its surroundings have not been met. At the same time, in spite of the obligations prescribed by *the Law on Planning and Construction* [9] and other normative documents, the spatial and urban plans encompassing the location and its surroundings do not contain specific planning solutions and, as such, they do not provide a sufficient planning basis for meeting the necessary requirements and obligations regarding the protection from radiation.

2. Spatial aspect of development and radiation protection at nuclear facilities locations

An adequate approach to the analysis and planning of locations of nuclear facilities and the consideration of their functioning and impacts on the surroundings implies the knowledge on and implementation of a series of principles and requirements. The International Atomic Energy

Agency (IAEA), in Vienna, Austria, defines several levels of documents that represent the standards for the peaceful use of nuclear energy and the reduction of risk of ionizing radiation in the world, such as the safety fundamentals, safety requirements, and safety guides, which are further elaborated through the national legislative systems.

After the construction of the nuclear facilities at the Vinča location in the 1950s and 1960s, there was no need to plan new facilities at any other location. The regulations were based primarily on the research character of the nuclear facilities and the protection and reduction of risk from ionizing radiation, while the low and intermediate level radioactive waste was stored at the location.

Through a comparative analysis of a number of documents, studies, and conditions [15–18], related to the location of nuclear facilities, it is possible to single out the following general spatial conditions that can be applied to the location of a radioactive waste repository:

1. Geological conditions [19]:

- The proximity of potentially active fissures and landslides must not be less than 500 m;
- There must be no possibility of ground subsidence resulting from the formation of cavities by pumping water or oil, or due to mining works;
- There must be no possibility of soil collapse due to dissolution and removal of soluble material (karst erosion or other types of erosion);
- Seismically active areas are eliminated (the maximum expected earthquake intensity cannot exceed VIII degrees on the Mercalli scale, and the permitted ground movements must not exceed 0.15 of the acceleration of the Earth's gravity).

2. Hydrological and meteorological conditions:

- The use of water for various purposes, especially for drinking and irrigation, must not be near the location (especially not downstream);
- There must be no possibility of torrents occurring at the location or the possibility of flooding due to river overflows or embankment breaches;
- Locations with extreme meteorological conditions are eliminated.

3. Conditions related to spatial protection:

- Areas for exploitation of natural resources are eliminated (mining of ores, minerals, coal, and oil);
- Areas within the scope of protected natural assets (national parks, nature parks, special nature reserves, *etc.*) are eliminated;
- Areas of immovable cultural property (UNESCO heritage list and all cultural properties of national importance) are eliminated.

4. Conditions related to the population, settlements and buildings [20, 21]:

- Larger settlements (25,000 or more inhabitants) must not be closer than 2.5 km;
- The proximity to installations with potential emissions of chemicals (particularly gaseous) must not be less than 2 km,
- The proximity of existing civilian and military airports must not be less than 8 km;
- Locations downstream of water dams are eliminated;
- The proximity of frequently used roads must not be less than 1.5 km.

5. Special conditions [22–24]:

- Pay attention to the proximity of the state border and other factors important from the military and security standpoint (areas of interest for the country's defence are rejected).

The above-mentioned requirements of a general type need to be taken into account in drawing up the spatial and urban plans, *i.e.*, in locating nuclear facilities, whereby it is necessary to develop them further and to possibly adapt them to the location specificity. The use of these requirements is of the local character because they primarily relate to the formation of protection zones immediately around the locations of nuclear facilities, as well as to the prescribing of appropriate protection measures. However, the aspects of environmental protection and protection from radiation, especially in the case of assessing the environmental impacts of possible accidents at nuclear facilities, transcend the local framework and immediate surroundings.

In accordance with *the Law on Radiation and Nuclear Safety and Security* [3], a disposal is the storage of radioactive waste, spent sources, or spent nuclear fuel in a disposal facility without the intention of its removal. The IAEA defines the disposal of radioactive waste as its storage in a conditioned state in a place from which it will no longer return to the human environment or to reprocessing [4, 5].

Currently, there are about 100 low and medium activity radioactive waste repositories in operation in the world. These repositories are of various types, from shallow buried engineered concrete trenches to deep geological repositories [25]. The disposal of radioactive waste is carried out in such a way that it ensures the long-term stability of the repository, *i.e.*, it prevents the radioactive isotopes present in the waste from having any contact with the biosphere, especially with groundwater [26]. The basic principle of preserving the stability of waste material is its immobility in an appropriate material or construction, which isolates it in relation to its surroundings.

In the Republic of Serbia, as in the rest of the world, no unique detailed criteria have been defined for the purpose of determining suitable locations for constructing the repositories for nuclear waste, particularly with regard to spatial conditions. In recent years, the issue of constructing a radioactive waste repository in Serbia has been raised again, with accompanying research on the state of the radioactive waste at the Vinča complex, as well as the consideration of future needs and ways to solve this issue worldwide [27].

Selecting the location for a radioactive waste repository is a priority in the coming period in the Republic of Serbia, and finding a solution for this requires the methods and techniques used in spatial and urban planning. As the first step in this phase, it is necessary to analyze all the available data on the spatial conditions and constraints at the national level (an area of 88,848 km²), and to perform a macro-zoning and select the zones where there are no spatial constraints to the construction of radioactive waste repositories, using data processing in the geographical information system. Such potential zones for the construction of radioactive waste repositories are then further analyzed and microlocated.

3. “Vinča” complex – location, functions, and problems

The Vinča complex contains the nuclear facilities of great importance regarding the impacts on the surrounding area and the implementation of necessary protection measures [6, 7]. They include: (1) the RA reactor (of the thermal power of 10 MW), used for experiments in nuclear physics and for materials testing, today out of operation; (2) the RB zero power reactor, used for experiments in neutron physics and radiation protection, today out of operation; and (3) the temporary storage facility for the low and intermediate level radioactive waste originating from the activities of the reactors, the Vinča Institute, *etc.* The storage facility consists of three hangars (H1, H2 and H3) and the secure storage for spent sealed radioactive sources. The waste is mainly stored in barrels, but there is also different bulk waste that could not be adequately treated and packed at the time of taking it over. The liquid radioactive waste is stored in four underground liquid waste tanks made of concrete with stainless steel liner.

However, over time, the problem of permanent storage of radioactive waste has become a basic problem related to the performance of the activities. The mentioned storage facility is only a temporary radioactive storage facility, whose lifetime has elapsed and whose capacities are fully used. According to the international criteria, the existing location, which was suitable only for building the temporary storage facility, is not satisfactory.

Considered in a broader spatial context, namely within the boundaries of the city municipality of Grocka, as a part of the administrative territory of the city of Belgrade, a particular specificity regarding the spatial and urban planning, as well as the international impact of the Vinča complex functions and other functions in the area, includes the spatial distribution of certain facilities and activities of regional, national, and international importance in the area that is at a relatively small distance from the mentioned nuclear facilities (see Figure 1). These facilities include: (1) the Vinča municipal solid waste landfill, covering the area of 68 ha, of the planned area of 130 ha, with 800,000 t of disposed solid waste annually (from 80% of the narrower area of Belgrade), at the distance of 2.2 km; (2) the Belo brdo archaeological site, one of the most important neolithic sites in Europe, in which the Vinča culture developed dating back to 5000 BC, at the distance of 1.5 km; (3) Kaluđerica, the unplanned settlement with the greatest number of illegally built buildings in the surrounding area of Belgrade with an incomplete infrastructure and the population of 27,000 inhabitants, at the distance of 2 km from the edge of the settlement and 3.5 km from its centre; (4) the pan-European corridor VII (along the Danube River), at the distance of 1.8 km, the pan-European corridor X (the highway Salzburg-Ljubljana-Zagreb-Belgrade-Skopje-Thessaloniki), at the distance of 4.6 km, the planned southern bypass highway as a part of the pan-European corridor X, at the distance of 0.8 km, and the Smederevo road with heavy traffic, at the distance of 1.2 km. From the aspect of environmental protection, there are two categories of major risks of accidents in a wider location: the complex itself, with the risk of chemical and nuclear accidents, and the Vinča municipal solid waste landfill, with the very great risk of chemical accidents.

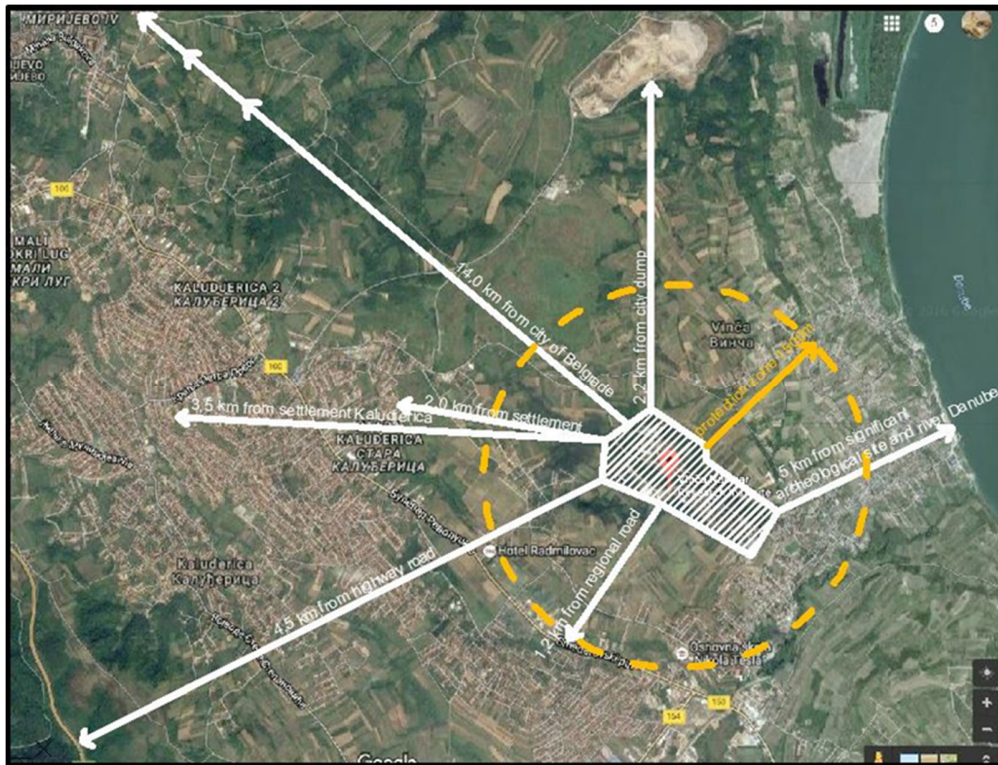


Figure 1. Location of the Vinča complex and facilities in its closer surroundings (sources: the author of the paper and the Google map).

Out of important planning solutions for the Vinča complex surroundings, the priority was given to the development of the road and rail corridors, namely, to the construction of the Belgrade southern bypass.

The Regional Spatial Plan for the Administrative Territory of the City of Belgrade [28] (with the Environmental Impact Assessment Report) classifies the Vinča complex into category D, which contains the entities that can have large-scale impacts on the environment at the regional level and that possess large quantities of dangerous and highly-toxic materials posing a high risk of chemical accidents with the possibility of cross-border impacts on the environment and human health. According to their ecological weight, such entities have to be located at large distances from the residential settlements, so that their functions at these distances during the normal operating regime do not threaten the health and safety of the inhabitants and do not cause the unpleasantness to their neighbourhood. New locations for business activities in the territory of Belgrade are not planned, neither is planned the extension or increase of the capacity of existing entities belonging to category D, except for the structures of energy system in the municipalities of Obrenovac and Lazarevac. For the purpose of improving the environmental quality, the existing facilities and production plants should implement all the necessary urban, technical, technological, remediation, and organizational measures of protection, in accordance with the requirements of *the Law on Environmental Protection* and other laws and regulations governing this field, and in accordance with the EU laws. The existing entities cannot satisfy the necessary criteria from the aspects of

environmental protection, safety, and human health and have to be moved to the appropriate safe locations.

Regarding the land use, the location of the Vinča Institute is situated within the coverage of the construction area. The urban planning rules and requirements for environmental protection for ecological category D are based on the minimum planning area of the complex and the mandatory protective distance between the source of danger and the residential settlement. For the facilities under category D, there is the predicted possibility of emissions of highly-toxic substances, thus a large-scale risk of accidents. The area of the complex is not limited, *i.e.*, the planned area encompasses at least 300 ha, and a protective distance, *i.e.* the protection zone, is at least 1,500 m. For such type of complexes, it is necessary to conduct *the Environmental Impact Assessment of the Project (Facility) Influence on the Environment*, *the Chemical Accident Risk Assessment*, and *the Strategic Environmental Assessment of the Complex Influence on the Environment*. The same determinants are also given within *the Spatial Plan for a Part of the Municipality of Grocka* [29].

According to *the Master Plan of Belgrade* [30], the main protection measure includes the reduction of the number of sources of ionizing radiation, and, thus, it is necessary to undertake the priority protection measures, including the transfer of the radioactive waste.

Based on the above-mentioned, we get an impression that in the existing plans the Vinča complex has neither been considered in sufficient detail nor specifically enough, but that the location has been treated only as a potential source of danger and only the recommendations for the elimination of the hazards and retaining the protection zones have been given. The reasons for such insufficient treatment in the plans should be further investigated, whereby the insufficient knowledge about the relationship of the special activity towards the surroundings, a fear based on the negative experiences at the global level, other referent laws in the field of protection and treatment of such complexes, as well as the effects which their operation can have on the environment should be borne in mind.

Concerning the purpose of land use, the Vinča location is designated for the existing complexes of public services, around which the green areas on its northern, western, and southern parts are planned. However, the main planning specificity is that the purpose of land use is not determined in the eastern area immediately by the location, at the part of the existing settlement, and that it will be determined after aligning the existing purposes with the specific regulations and additional investigation. Such undetermined planning solutions are a specific urban planning precedent and the result of a lack of analysis and studies on the impacts of the special purpose areas on their surroundings, as well as the result of impossibility of solving and harmonizing the relationships between different purposes in the area through plans. Concretely, the impossibility of establishing a protection zone in the part of the Vinča settlement situated by the Vinča location is evident. Indeed, the incompatibility of contents requires an urgent realization of the strategic solutions related to the dislocation of the temporary storage facility for disposal of radioactive waste from the location.

4. Analysis of the general spatial and planned conditions for planning the location of radioactive waste repositories for the territory of the Republic of Serbia

The collection, analysis, and processing of the data related to these spatial conditions is a complex and time-consuming process, because the data are partially available, they are of different ages and levels of processing, and they are often unsuitable for digital processing, which is especially true for larger areas. Also, preparing a spatial plan is the only process of the synthesized character, whereby such data for different areas are collected and processed in a single geographic information system. Therefore, it is essential for research of the spatial conditions for planning the location of a radioactive waste repository to be linked with the development of *the new Spatial Plan of the Republic of Serbia*, and this should be done in the first step for the data related to the existing state (see Figure 1).

In terms of geological conditions, the greatest spatial limitations in Serbia (26.58 % of the surface) are in areas where the maximum expected earthquake intensity is over VIII degrees on the Mercalli scale. The highest intensity of VIII degree is related to high basic hazard zones and unfavourable local soil conditions.

The areas of mining activities, which limit the possibility of locating a radioactive waste repository, are represented by the significant areas of surface coal mines in three large basins (of Kolubara, Kostolac, and Kosovo-Metohija), and by the surface mining of metallic raw materials in Bor and Majdanpek, as well as in a small way by several tens of mines for mineral, metallic, and non-metallic raw materials at different locations.

All categories of soil erosion are represented on the territory of the Republic of Serbia, with the most pronounced ones being karst erosion. Within the framework of areas that have an explicit natural hazard, *i.e.*, the predictive erosion areas of strong and excessive erosion (with the land losses of over 20 t/ha per year) is 13.32% of the territory, *i.e.*, 11,776 km². This mostly includes the terrains at the altitudes over 600 m above sea level (asl), where there are also restrictions due to the danger of torrents, unstable soil, and often protected natural features, made up of the mountainous areas of southwestern and southeastern Serbia.

The potential areas of flooding that are unfavourable for locating a repository for radioactive waste in Serbia cover 16% of the total territory, *i.e.*, an area of 14,146 km². The floods have affected the Central Banat and South Bačka areas the most, followed by the South Banat and Belgrade areas.

About 11,500 watercourses with torrents have been registered in Serbia, in the basins ranging in size from several hectares to several hundred square kilometers. This means that practically the whole of Serbia south of the Sava and the Danube (the hilly and mountainous part of Serbia) is endangered. The areas of very high susceptibility to torrents are represented on 4.2% of the surface of Serbia, and of high susceptibility on 24.2%, meaning that about 28% of the territory of Serbia is very susceptible to torrents.

Other significant restrictions for the construction of a radioactive waste repository are the sanitary protection regimes in the catchments of existing and planned accumulations intended for water

supply. Such areas are within the regional systems for water supply to the population, which are located in central and southern Serbia. The basins of 36 newly-planned accumulations, in addition to the existing ones, occupy about 8,000 km², *i.e.*, 9% of the territory of Serbia, from which the possibility of locating a radioactive waste repository is excluded.

The areas with unfavourable spatial conditions and restrictions in the terms of distribution of population, settlements, and facilities in Serbia are smaller in size than the previously mentioned limitations, but due to their diversity in space, they cause significant limitations. These are the settlements and cities with more than 25,000 inhabitants and the zone that surrounds them of the radius of 2.5 km (from the edge of the construction area), and airports of different ranks (international, regional, and military) with the surrounding zone (of the radius of 8 km), in which the construction of radioactive waste repositories is not permitted. In addition, the spatial limitations relate to the network of frequent roads which in Serbia covers 30,000 km of modern roads (most state roads are class I or II), and about 3,700 km of railways (international, regional, and local), with the zones that are unfavourable for constructing a repository covering the distance of 1.5 km from the transport corridor.

The processing of the spatial data on the existing state and conditions of a geological and hydrological nature, as well as the conditions related to the population, settlements, and facilities (only the basic data related to the larger areas are listed) indicate that on an area of about 52,900 km², which is 60% of the territory of Serbia, there are significant restrictions with regard to the location and construction of radioactive waste repositories.

In addition to the previously mentioned data related to the current situation, as a second step in research of the spatial conditions for planning the location of a radioactive waste repository, it is necessary to analyze the concept of the future spatial development of the Republic of Serbia and individual planning solutions of national importance. The aim of such research is to record the important planned purposes and activities in space, as well as the planning constraints for defining the suitable location for constructing of a radioactive waste repository. In this paper, the authors use the newly-formed spatial databases and preliminary solutions from *the Spatial Plan of the Republic of Serbia from 2021 to 2035* [14]. The most important aspects to analyze are the urban and traffic systems (frequently the used roads), development zones, protected areas, and natural values.

The structure of basic land use in the Republic of Serbia (88,848 km²) is dominated by the agricultural land, covering 43,113 km² (48.7%), and the forest and unwooded forest land, covering 38,240 km² (43.1%), while the unfavourable areas from the standpoint of locating a repository are the wetlands and water surfaces, covering 2,377 km² (2.63 %), and other areas (the construction land and artificial surfaces), covering 4,757 km² (5.4%).

The spatial plan establishes the protection of space on the total area of about 27,115 km² or 30% of the territory. These are the areas where the possibility of locating radioactive waste repositories is excluded. The protection of space is mostly planned for the protected natural assets or those that are planned for protection (about 15,442 km²) and immovable cultural goods (about 11 km²), as well as for catchment areas of the sources of regional water supply systems (about 11,662 km²).

Important for the spatial analysis in this paper is the planning in relation to the completion and development of the planned road and railway infrastructure in Corridor X, and the branches of that corridor on the territory of the Republic of Serbia, along the primary and secondary development belts, as well as the completion and reconstruction of the existing state road network (the so-called fast highways).

The metropolitan areas also stand out as a planning category that excludes the possibility of locating a repository for radioactive waste.

The processing of the spatial data on all the above limitations caused by the planned spatial development of the Republic of Serbia and the planning solutions that mostly relate to the urban and transport systems, development zones, protected areas, and natural values indicate that on the area of about 45,300 km², which is 51% of Serbia, there are significant planning constraints for locating and building a radioactive waste repository.

The analysis and processing of two important groups of spatial data, the first on the existing constraints and the second on the planning conditions and restrictions, have led to the basic result that on the total area of about 69,300 km², which makes up 78% of the total area of Serbia, there are restrictions that make this area unfavourable for locating a radioactive waste repository (see Figure 2). This research has included the analysis and comments on the data available at the level of entire territory of the Republic of Serbia, and the areas that were assessed as unfavourable according to the individual constraints overlap to a great extent. This means that such areas are unfavourable because of at least two, and often more spatial constraints, making further detailed research necessary.

This analysis has been established that there are no restrictions on the area of about 19,060 km², which makes up 22% of the surface of Serbia, indicating that this area is potentially favourable for locating a radioactive waste repository. This includes certain areas that are located at over 600 m (asl) but which have no other restrictions, and they are considered conditional in this category of surfaces.

The spatial and planning aspect of finding an initial resolution to the issue of locating a radioactive waste repository in Serbia is in some way completed by the results of this analysis. In addition to the fact that it is necessary to start with a comprehensive and detailed research of this type, this analysis indicates which conclusions we can expect in the future. In the field of spatial research, according to the authors of this paper, it is important to know that only 22% of the Serbian territory has been assessed as being favourable for locating a radioactive waste repository, *i.e.*, that it is necessary to direct more attention towards the previously mentioned zones (with an emphasis on eastern and southern Serbia).

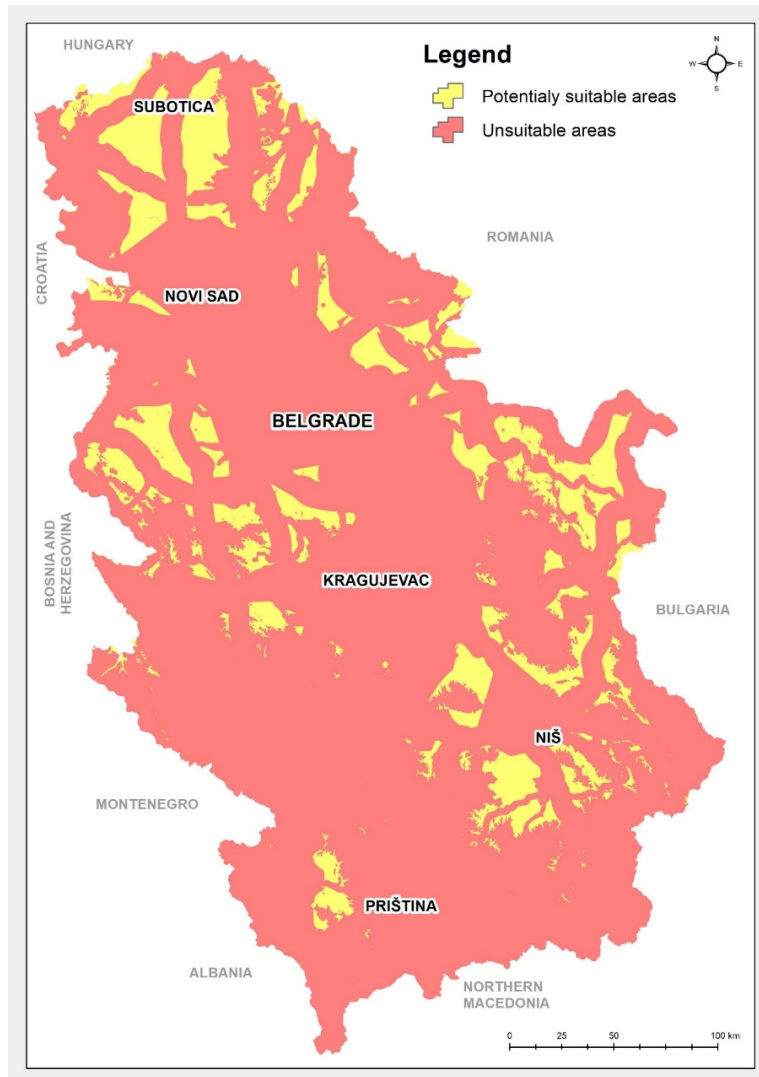


Figure 2. Overview of the zones and areas in the Republic of Serbia that are favourable for further planning with regard to the location of a radioactive waste repository.

5. Conclusions and recommendations for the spatial development and protection zone of the “Vinča” complex

The main conclusion of the research on the Vinča complex location is that it is absolute necessary to prepare a special purpose area spatial plan, which is under jurisdiction of the Government of the Republic of Serbia. It is explained that the general requirements related to the limitations in space and the formation of protection zones around the nuclear facilities have not been met in the location itself and in its narrower surroundings. The existing situation at the location, primarily the scope of illegal construction and the position of both the existing and the planned roads with heavy traffic, is unfavourable and has conditioned such limitations that it is not realistic to expect the possibility of meeting the above-mentioned requirements in the coming period. For any planning

activity to start and for mitigating the conflicts in space and undertaking the adequate protection measures, **it is necessary to conduct further research through making a special study, as well as to carry out the measurements in a wider area, all with the aim to consider the international impacts of nuclear facilities and purposes in the surroundings**, and both in the existing situation and through assessing the impacts of possible accidents in nuclear facilities.

The fact that the purpose of land use in the part that is in immediate vicinity of the Vinča complex has not been determined, but will be determined after aligning the existing purpose of land use with the special regulations and additional investigations, namely, the conclusion that the existing plans have neither considered the complex in sufficient detail nor specifically enough, but have treated it only as a potential source of danger, and the recommendation for retaining the protection zones, indicate the need to create the new planning documents for the complex and its wider surroundings. Because of the dislocation of certain facilities and activities of the regional, national, and international importance from the area at a relatively small distance from the nuclear facilities at the Vinča complex (the Vinča municipal solid waste landfill, the Belo Brdo archaeological site, and the pan-European corridors VII and X), as well as because of the national importance of the Vinča location, namely, because of the need to align the important functions in the area, **it is necessary to draw up a special purpose area spatial plan**. This type of spatial plan, the adoption of which is under jurisdiction of the Government of the Republic of Serbia, is drawn up for the areas requiring a special regime of organization, development, use, and protection and which are of the national importance. It is also mandatory to carry out **the strategic environmental assessment simultaneously with the process of drawing up the plans**.

The experiences in drawing up the spatial and urban plans for the locations of nuclear facilities do not exist in Serbia. The special purpose area spatial plans have been prepared for the locations of protected natural resources, pan-European transport corridors, areas of intense surface exploitation of minerals, *etc.* In the neighbouring countries, such experiences are modest and based on the creation of documents of technical nature (projects) and documents in the field of environmental protection (environmental impact assessment). For this reason, it would be of great importance **to develop a special general methodology for drawing up spatial plans for locations of nuclear facilities and their surroundings**. At the same time, a new approach to considering and planning such locations would enable **the re-examination of the general criteria and requirements analysed in this paper**, as well as their more detailed determination depending on the existing situation and activities in the real surroundings, on the one hand, and the determination of the type and nature of nuclear facilities, on the other hand.

6. Conclusions and recommendations for planning the location of a radioactive waste repository on the territory of the Republic of Serbia

Through the research and presentation of its results in this paper, the authors have tried to contribute to initiating and solving the issue of (permanent) disposal of radioactive waste in Serbia. Based on the previous research and knowledge of the technical and radiation properties of the radioactive waste stores at Vinča location, as well as on the proposal for the concept of a single repository [27], it seems that it is the right moment to undertake a systematic research to determine the location of a radioactive waste repository. This is supported by the fact that *the Spatial Plan of*

the Republic of Serbia from 2021 to 2035 [14] is currently under preparation, which brings the problem of radioactive waste storage into a spatial context and provides an opportunity for the timely direction of further research and making the necessary decisions.

Over recent years, the spatial analyses and data processing with the use of the geographic information systems have represented a common methodological procedure in spatial development planning [31–35]. However, such a procedure has not yet been applied in Serbia to those data that are of significance and have a direct influence on the possibility of determining the zones and locations for a radioactive waste repository. Therefore, this research aimed to first systematize the general spatial conditions and criteria for selecting the location for a radioactive waste repository and to later collect and process such data for the territory of Serbia. A special contribution of the research is that it was conducted simultaneously with the preparation of the Spatial Plan of the Republic of Serbia, which made it possible to use the newly-collected data from 2020. In addition, the new category of planning restrictions was also considered, which further prevent the location of a radioactive waste repository on the significant areas.

The results of the research, which indicate that 78% of the surface of Serbia, due to one or more constraints, is unfavourable for locating a radioactive waste repository, have a great applicative significance. Thus, the scientific and professional attention can be focused in a relevant way on those zones in which the limiting factors have not been identified and which should be the subject of future detailed research. In addition, with the previous knowledge of the problems of the Vinča complex [8], this research has been able to give a feedback during the preparation of *the Spatial Plan of the Republic of Serbia* [36], in such a way that the measures of its implementation envisage the priority development of a *Spatial Plan for the Special Purpose area of the Vinča Location* and the development of a *Study for Determining the Location of a Radioactive Waste Repository in Serbia*.

For further phases of the research of the issue of a radioactive waste repository in Serbia, the limitations of the already undertaken research should be taken into account, in terms of two important aspects. The first refers to the general spatial conditions used in this paper, which are of the general type and refer to nuclear facilities in the broadest sense. As such, they have conditioned the stricter limitations, which in the coming period can be reviewed and moderated depending on the nature and technical characteristics of the radioactive waste repository. The second aspect relates to the availability and nature of the data used in the spatial analysis. For further research, it would be necessary to obtain the missing data and innovate those that are not in a usable digital format.

The research presented in this paper is of the initial and scientific character. In the beginning, the solving of the issue of permanent disposal of radioactive waste in Serbia requires a systematic approach, which in terms of the spatial aspect implies at least two methodological phases. The first phase is a study (the preparation of a study) that includes the macro-zoning of space, with the additional research and coordination of numerous institutions, and later the micro-zoning of space, with a detailed analysis, multi-criteria evaluation, and site selection. The second phase is the planning and design phase (the preparation of a spatial plan for the special purpose area), through which the location is checked and confirmed, the rules of arrangement, construction, use, and

protection of the space are defined, and later the design for the future radioactive waste repository are made. It is in this direction that it is possible and necessary to conduct further scientific research, in order to give full support to a permanent resolution of the issue of radioactive waste disposal in Serbia.

Note

This paper contains an overview of the research results presented in paper [8] as well as the results prepared and proposed in the paper that will be published: N. Stefanović, N. Krunić, and N. Danilović Hristić, *The Spatial and Planning Aspect of Solving the Issue of Radioactive Waste Repository in the Republic of Serbia*.

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