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RESEARCH ARTICLE
Local Governments, Urban and Environmental

Management of Nuclear Waste in Nuclear Energy System for Sustainability of the Ecosystem (Evaluation in terms of Environment and Human Health) in Terms of Monazite Mineral

ABSTRACT

In this study, the working methods of Nuclear Power Plants, which have been used effectively since the 1970s to meet the energy needs of countries, and the types of waste they produce have been specified, and the storage areas of these wastes which consist of matural mineral of Monazite have been evaluated. Literature reviews of the monazite mineral, which is found in large quantities in Türkiye, have been conducted to determine its resources, resistance to radiation and usability. The monazite mineral, which has a large share in world reserves, provides a secure structure for the storage of nuclear wastes in the long term. First of all, the monazite mineral has been investigated in depth in the study, and the working methods of nuclear power plants and the storage areas of wastes have been examined. Then, the safety of nuclear power plants in terms of human health and safety has been discussed. The compliance of nuclear facilities with sustainable development goals for Türkiye's sustainable energy future has been investigated, and nuclear accidents that have occurred in Türkiye in the last 25 years have been evaluated in the context of the social goals of sustainable development.

Keywords: Nuclear Energy, Monazit Sustaniable Development, Türkiye

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INTRODUCTION

The need for energy is increasing day by day with the increasing population, urbanization and industrialization in the world, but energy consumption is decreasing at the same rate. In this case, important problems such as energy deficit in the world and in Türkiye come to the agenda (Şenol & Akman, 2019). Energy is a mandatory factor in all sectors and shows all kinds of development potential of a country (Koç and Kaya, 2015). In order to provide energy to consumers in a reliable way, the connection between sustainable development and energy has been discussed. However, due to the gradual decrease in energy resources such as coal, oil and natural gas, the concept of energy efficiency has been brought to the agenda and these issues have been included in the studies on sustainable development (Kavak, 2005). Energy efficiency is a very important issue for the future of our planet. The ever-increasing population in Türkiye, our increasing need for energy with the developing industry and technology, and the fact that we are largely dependent on foreign energy with the depletion of our existing energy resources have made it compulsory for our country to work on the efficient use of energy. Using the right storage techniques for the correct and efficient use of energy is a method to make it cheaper. With the reduction of the cost, the reduction in greenhouse gas emissions caused by climate change will reveal the necessity of efficient use of energy (Aydin, 2016).

Energy has become an important issue in the world due to rapidly increasing industrialization, technological developments and population growth. Since the 1800s, increasing industrialization has led to a significant amount of energy demand. In order to meet this demand, fossil fuel-based energy production was made at first. In the following years, renewable energy sources have become an alternative. Energy production at an affordable cost and amount has been the most emphasized issue today. The sensational development in energy, which has become the locomotive sector in the development of the industry, is the energy resulting from the neutron bombardment of Uranium-235 (Nuclear, 2017). The 1950s and 1960s saw the rapid expansion of nuclear power plants. The fact that the amount of energy produced as a result of the splitting of one uranium atom is 10 million times the energy produced by the combustion of one coal atom. In other words, the fact that the energy that can be obtained from

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half a kilo of uranium can produce the same energy as million liters of oil, has led nuclear energy to be considered as the energy source of the future (Gülay, 2008).

Later on, an unseen side of nuclear energy emerged. The fact that its response to the great energy needs it created was positive at first caused the negative aspects to emerge later. On March 28, 1979, an accident caused by a faulty valve at the Three Mile Island nuclear power plant in the United States revealed how dangerous nuclear energy can be. The melting of nuclear fuel due to insufficient cooling could cause significant damage to plant workers, the surrounding community and nature. With the understanding of the damages, more sensitive processes began. Instead of old technology nuclear power plants, safer power plants have emerged. All these developments led to the search for different energy sources. It can be said that these initiatives are centered on two main energy sources: renewable energy and nuclear energy. Electricity obtained from sources such as wind, solar, hydraulic, geothermal and biomass are environmentally friendly energy sources with very low operating and maintenance costs. However, these sources can be very much affected by seasonal events. The fact that sustainability is an element of energy supply security when designing energy policies shows that it is difficult to develop a policy based only on these resources (Vural et al., 2022).

The disposal of nuclear waste is a difficult problem that has not yet been adequately resolved. Radioactive materials need to be stored for centuries in order to decay into less harmful substances. Various studies have been carried out on burial in deep wells, caves, old depleted salt mines, deep in the oceans or in underground tanks (Official Gazette, 2013). One of the challenges is that such wastes are mostly liquids that can be easily and quite safely stored temporarily in underground tanks, but since radioactive wastes have a half-life longer than the wear time of tanks, current efforts are directed towards converting radioactive wastes into liquids that can be stored more safely. The two main techniques emphasized in this regard are vitrification (covering nuclear waste with safe glass material) and electrokinetic treatment. Vitrification is the encapsulation of waste under high temperatures (1200-2000 ^{0}C) using low permeability ceramic and glass materials. However, vitrification is a very expensive process (World Nuclear Assocıatıon, 2024). Electrokinetic treatment involves electro migration of ions, electro osmosis of water and electrophoresis of electrically charged particles. The ideal complexing agent should be suitable for the waste, negatively charged with the target substance, non-toxic, inexpensive, non-corrosive, separable from electrokinetically cleaned metal complexes and biodegradable, and finally easily separable from the target waste in the final treatment (when required).

In this study, the way of operation of Nuclear Power Plants, which have been used effectively since the 1970s in order to meet the energy needs of countries for the sustainability of the ecosystem, and the types of wastes produced by them, and the natural storage areas of these wastes were evaluated. In addition, monazite mineral, which is found in large quantities in Türkiye, were analyzed in the literature and its source, resistance to radiation and usability were determined. Monazite mine, which has a large share in the world reserves in Türkiye, offers a secure structure for the storage of nuclear waste in the long terms.

The Importance of Nuclear Power Plants and Energy Production

Energy is one of the most important elements that we actively use in our daily lives, which is vital for the lighting of society's dwellings and the economic and social development of the place where we live, as well as enabling businesses to continue their activities. The extreme temperatures, precipitation and global warming that have occurred in the last ten centuries affect all of humanity. Increasing temperatures and greenhouse gases basically cause disruption of the carbon cycle. The factors that increase greenhouse gas emissions are thought to be mainly industry, transportation, agriculture, excessive urbanization, fossil fuels and deforestation. Therefore, humankind has already recognized the climatic crises that threaten us for the future of our planet (Pla et al., 2021; Yaman et al., 2024).

Resources have been the cause of wars and attempts to dominate throughout human history. These resources were diverse: spices, precious oil, silk, gold, people. However, with the Industrial Revolution, energy resources came to the fore (Pamir, 2003). Nuclear energy is a type of energy obtained by combining or disintegrating atomic particles through various reactions. Nuclear energy is converted into electrical energy through nuclear reactors. Basically, nuclear energy released as a result of fusion is converted into heat energy in nuclear fuel and other materials, this heat energy is converted into kinetic energy and then into electrical energy in the generator system. Nuclear fuels are easy to transport and can be reused. The energy source is used in different sectors such as first aid, waste management and radio activity control. The possibility of misuse of nuclear energy sources can pose a threat to world peace. This situation requires the use of nuclear energy under an intensive control system and in line with international agreements which limits the use of nuclear energy (Savrul, 2010).

If the Turkish electricity generation sector attracts investments of 7-8 billion $ per year and the cost of solar power plants excluding lines is assumed to be 0.8 million $/MW, it is understood that an investment of 417 billion $ is needed for solar alone. It can be predicted that at least half as much storage investment will be required. It will take 50 years to realize a 417 billion $ solar generation investment. If we consider the construction of the lines, this figure can increase 1.2 times and reach 60 years (World Energy Council, 2018).

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Atoms are the smallest building blocks of matter. The heat energy released by the fission of atomic nuclei spontaneously or by external intervention is called nuclear energy. Most of the power plants convert heat energy into electricity. The heat generated by various reactions vaporizes water. With the help of this vapor, the turbine is rotated (TENMAK, 2016).

In nuclear power plants, the energy needed to produce steam comes from the heat generated by the fission of uranium atoms. The fission of each atomic nucleus releases fission products, nuclear energy and two to three neutrons. These neutrons, which are released because of the fission, keep the atomic nuclei splitting. In this way, heat energy is continuously produced. This process is called a chain reaction.

In nuclear fuel material, heat is released because of the splitting of atoms (fission). This heat is transferred to the water inside the reactor. The heated water is under high pressure, it is not allowed to boil (yellow cycle in Figure 2). The water in a closed loop under high temperature and pressure transfers its heat energy to another water loop in the secondary loop (blue loop in Figure 2). The water in the secondary loop boils and vaporizes with the transferred heat. The resulting steam is sent to the turbine system and turns the turbine. As the turbine spins, electricity is generated in the generator and its magnetic field.

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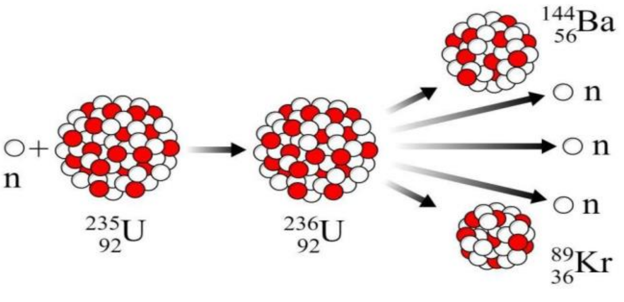

Figure 1. Fission Event
Source: (Evrim Ağacı, 2020).

In nuclear fuel material, heat is released as a result of the splitting of atoms (fission). This heat is transferred to the water inside the reactor. The heated water is under high pressure, it is not allowed to boil (yellow cycle in Figure 2). The water in a closed loop under high temperature and pressure transfers its heat energy to another water loop in the secondary loop (blue loop in Figure 2). The water in the secondary loop boils and vaporizes with the transferred heat. The resulting steam is sent to the turbine system and turns the turbine. As the turbine spins, electricity is generated in the generator and its magnetic field (Evrim Ağacı, 2020).

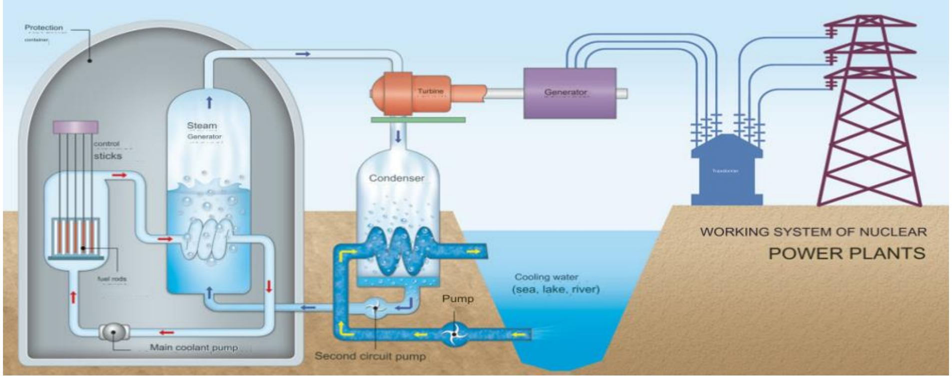

Figure 2. Nuclear Power Plant Schematic
Source: (Ministry of Energy and Natural Resources, 2023).

Briefly, the functioning of a nuclear power plant is as follows. A nuclear reactor is a machine designed to ensure the controlled realization of a nuclear reaction (fission) and the continuous and regular production of the heat released during this process in a safe, environmentally friendly and reliable manner. A nuclear reactor is a machine designed to ensure the continuous and regular production of this energy. For continuous and regular production, two things must first be ensured:

1) The continuation of the fission reaction in a one-to-one (controlled manner),

2) Proper removal of the generated heat from the environment (MIT,2023) .

The steam passing through the turbine is condensed by the cooling water cycle taken from large water basins such as sea, lakes and rivers (green cycle in the figure). The condensed water is returned to the second cycle and the water taken from the sea, lake or river is returned to nature. As can be seen from the figure, the water in the primary, secondary and cooling water cycles are circulated in different pipes and do not mix with each other. Therefore, the water supplied to nature does not contain radioactivity (Ministry of Energy and Natural Resources, 2023).

The goal of establishing a nuclear power plant in Türkiye started to be realized with the signing of the “Agreement on Cooperation between the Government of the Republic of Türkiye and the Russian Federation on the Establishment and Operation of a Nuclear Power Plant at the Akkuyu Site” on May 12, 2010. The Agreement was adopted by the General Assembly of the Turkish Grand National Assembly (TBMM) on July 15, 2010 and published in the Official Gazette No. 27721 dated October 6, 2010. Subsequently, an Environmental Impact Assessment (EIA) positive decision was obtained from the Ministry of Environment, Urbanization and Climate Change (December 1, 2014) and an electricity generation preliminary license was obtained from the Energy Market Regulatory Authority (EMRA) for 36 months. The construction license was approved by TAEK on April 2, 2018, and the groundbreaking ceremony for the first unit of the Akkuyu Nuclear Power Plant was held. This unit is planned to be commissioned in 2023 (Ministry of Energy and Natural Resources, 2018).

Requirements and Principles of Radioactive Waste Management as follows:

- ✓ Protection of human health
- ✓ Protection of the environment
- ✓ Protection beyond national borders
- ✓ Protection of future generations
- ✓ Not to burden future generations
- ✓ Establishment of national regulatory infrastructure
- ✓ Control of radioactive waste production
- ✓ Interaction of radioactive waste management steps (IAEA, 1995).

Development of Nuclear Energy in Türkiye

Türkiye nuclear history began with the establishment of the Atomic Energy Commission in 1956. Subsequently, our nuclear adventure gained an international dimension with the founding membership of the International Atomic Energy Agency in 1957 (IAEA, 2024).

Every government between 1956 and 2018 saw the establishment of a nuclear power plant as a national issue, but this goal could not be achieved. In the past, four different nuclear power plant tenders could not be finalized due to coups, international pressures and difficulties in project financing. (Vural and Çifçi, 2021). The process of fission is given in Table 1.

Table 1. Historical Development of Nuclear Energy in Türkiye

Year	Step	Year	Step
1962	✓ The Çekmece Nuclear Research and Training Center has commissioned a 1 MW "pool" type experimental reactor, TR-1.	1997	✓ An international tender was launched by invitation for the evaluation of tender offers and consultancy services for contract negotiations. ✓ On, bids were received from 3 consortiums for the Akkuyu Nuclear Power Plant.
1970	✓ Electricity sector was reorganized and the Turkish Electricity Authority (TEK) was established, and the works carried out by EİE(Electricity Survey and Development Administration)and Etibank until then were gathered under one hand.	2000	✓ This tender was also cancelled by the Council of Ministers Decision after the announcement of the decision was postponed 8 times due to various reasons, and the TEAŞ Nuclear Power Plants Department, which was established for the second time, was closed again.
1972	✓ The Nuclear Energy Department established under TEK started to work.	2002	✓ The "Turkish Atomic Energy Authority (TAEK)", which serves as the licensing authority under the Prime Ministry, has been affiliated to the Ministry of Energy and Natural Resources.
1976	✓ A "location license" was granted for the Akkuyu Field by the Prime Ministry Atomic Energy Commission. The project and tender specifications were prepared in cooperation with a consultant-engineering consortium consisting of 3 Swiss and 1 French companies.	2004	✓ Energy and Natural Resources Ministry and the Turkish Atomic Energy Authority (TAEK) have announced the construction of three nuclear reactors totaling 5000 MWe, with construction to begin in 2007 and the first unit to be commissioned in 2012. ✓ TAEK announced that it has initiated studies for the establishment of a Nuclear Technology Center (SNTM) in Sinop consisting of several facilities
1980	✓ By ratifying the NPT (Nuclear Power Plant), Türkiye has pledged not to manufacture nuclear weapons and not to be an intermediary in their proliferation.	2005	✓ Ankara Nuclear Research and Training Center (ANAEM) and Ankara Nuclear Agriculture and Research Center (ANTAM) were merged and named Sarayköy Nuclear Research and Training Center (SANAEM). ✓ TAEK has announced that site identification studies are underway.
1981	✓ A Safeguards Agreement was signed with the International Atomic Energy Agency, which accepts the control of International Atomic Energy Agency experts to determine whether nuclear power plants in Türkiye are operated for peaceful agreements.	2006	✓ TAEK announced that it carried out detailed technical studies throughout Türkiye regarding where the nuclear power plant would be built, and that 8 locations were determined as the location of the plant, taking into account 43 criteria.
1982	✓ Turkish Atomic Energy Authority (TAEK) was established and appointed as the licensing authority	2008	✓ The General Directorate of Turkish Electricity Trading and Contracting Inc. (TETAŞ) launched an electricity purchasing tender, which it called a "competition," for the nuclear power plant to be built in Akkuyu, Mersin. In the "competition" held on September 24, 2008, only the Atomstroyexport-Inter Rao-Park Teknik Group submitted a bid with the Russian type VVER design.
1983	✓ A Safeguards Agreement was signed with the International Atomic Energy Agency, which accepts the control of International Atomic Energy Agency experts to determine whether nuclear power plants in Türkiye are operated for peaceful agreements.	2009	✓ The Council of State has suspended the execution of two more articles of the law on the establishment of Nuclear Power Plants, covering the issues of 'location allocation' and 'unit sales price'. ✓ Turkish Electricity Trade and Contracting Inc. (TETAŞ) announced that it has cancelled the competition held on September 24, 2008.
1984	✓ Türkiye became a member of the OECD Nuclear Energy Agency (NEA)	2010	✓ Russia and Türkiye have signed an agreement titled "Joint Declaration on Cooperation on Establishment of Nuclear Power Plant in Türkiye". ✓ On May 12, the "Cooperation Agreement on Establishment and Operation of Nuclear Power Plant in Akkuyu Field" was signed between the governments of Türkiye and Russia. ✓ On July 15, the agreement signed between Türkiye and Russia on cooperation on establishment and operation of nuclear power plant in Akkuyu was accepted in the TBMM General Assembly. It was approved by President Abdullah Gül on July 20, 2010.

1986	✓ Due to the negative environment created by the Chernobyl nuclear power plant accident, studies on nuclear power plants in Türkiye have been suspended.	2013	✓ On May 3, the Government of the Republic of Türkiye and the Government of Japan signed an agreement regarding the establishment and operation of the NPP in Sinop. Based on this agreement, 4 reactors with a capacity of 1120 MW (total 4480 MW) will be established. ✓ On, Akkuyu's "Updated Site Report" was found appropriate by TAEK.
1988	✓ The TEK Nuclear Power Plants Department was closed down and some of its experienced and educated personnel were dispersed within TEK, and a significant portion of them left TEK.	2014	✓ A positive decision was taken for the Environmental Impact Assessment (EIA) Report for Akkuyu NPP in December.
1993	✓ Akkuyu Nuclear Power Plant Project was published in the Official Gazette and included in the investment program again.	2017	✓ The Turkish Atomic Energy Authority (TAEK) approved the Field Parameters Report for Akkuyu NPP. ✓ The Energy Market Regulatory Authority (EPDK) granted Akkuyu an Electricity Production License. ✓ In October 2017, a "Limited Operation Permit" was received from TAEK for the first unit of Akkuyu NPP.
1994	✓ A proposal was requested for the selection of a consultant company to evaluate the current situation in the world regarding the nuclear power plant, to make recommendations for Türkiye, and to update and prepare the technical specifications.	2018	✓ In March 2018, the first group of students who received nuclear engineering education in Russia graduated. ✓ In April 2018, TAEK granted a 'Construction License' for the construction of Unit 1 of Akkuyu NPP. ✓ On 03.04.2018, the first concrete was poured for Unit 1 of Akkuyu NPP. ✓ On 30.11.2018, a "Limited Work Permit" was obtained for the second unit of Akkuyu NPP.
1995	✓ A contract has been signed with KAERI of South Korea and GAMB of Turkey to carry out pre-tender studies.	2018	✓ NDK (Nuclear Regulatory Authority) was established its independent regulatory body to assume the regulatory control activities previously managed by TAEK.
1996	✓ Akkuyu an international tender has been launched for the Nuclear Power Plant.	2020	✓ TAEK was closed and instead TENMAK (Turkish Energy, Nuclear and Mineral Research Agency was established.

Source. (NuclearAcademy 2024).

On May 12, 2010, Türkiye and Russia signed an intergovernmental agreement under which Rosatom will build and operate a four-unit VVER-1200 (1200 MWe) reactor of the third generation AES-2006 type in Akkuyu according to the build-operate model. An application for site and construction licenses was filed with the Turkish Atomic Energy Authority (TAEK) in December 2015. The first unit is expected to be operational in 2023. - In April 2015, an agreement was signed with a consortium of Areva and Mitsubishi for the construction of a third generation ATMEA 1 type 4x1120 MWe nuclear power plant. The licensing report submitted in December 2015 is under review by TAEK. Towards 2015-2016, the emphasis on measures to reduce carbon dioxide emissions against global warming, efforts to phase out coal and other fossil fuel power plants for this purpose, and the low cost of electricity generation in nuclear power plants have led to the erasure of the negative attitude towards nuclear power plants in many countries, which was created by the Fukushima accident (Kütükçüoğlu, 2020).

Radioactive Waste Management

Wastes whose radioactivity levels are higher than the activity concentration of very low-level radioactive wastes but are not classified as high-level radioactive waste. Low- and medium-level radioactive wastes consist of consumables such as plastic boxes, gloves and filters used in nuclear facilities, as well as radioactive materials released as a result of dismantling activities of nuclear facilities, or radioactive materials used industrially in non-destructive testing applications and for diagnosis and treatment in medicine.

The first process in radioactive waste management is pretreatment, where radioactive wastes are subjected to processes such as collection, separation, chemical regulation and de-radioactivation in order to prepare them for treatment. Then, in the treatment step, the volume of radioactive waste is reduced by using methods such as ion exchange, incineration, evaporation, evaporation, precipitation, filtration and condensation, and the form, content and properties of the radioactive waste are changed when necessary. In the storage process, radioactive waste is kept in a system or facility with the intention of retrieval. Storage can be applied among the radioactive waste management steps before disposal

In the transportation step, radioactive waste can be transported between radioactive waste management steps prior to disposal. Radioactive waste is transported by means of specially designed containers according to their type, which can be used during transportation as well as during storage and/or disposal. The final step is the final storage of radioactive wastes in the disposal process of the attribution in an appropriate manner with no intention of retrieval. Very low, low and intermediate level waste that is ready for disposal is sent to surface or near-surface (30 m below the surface) or intermediate depth (30 to several hundred meters below the surface) disposal facilities for disposal. Low- and intermediate-level radioactive waste is now safely disposed of in disposal facilities in Germany, the United States, Sweden, Finland, France, the Netherlands, the United Kingdom, Spain, Switzerland, Japan, Canada and many other countries.

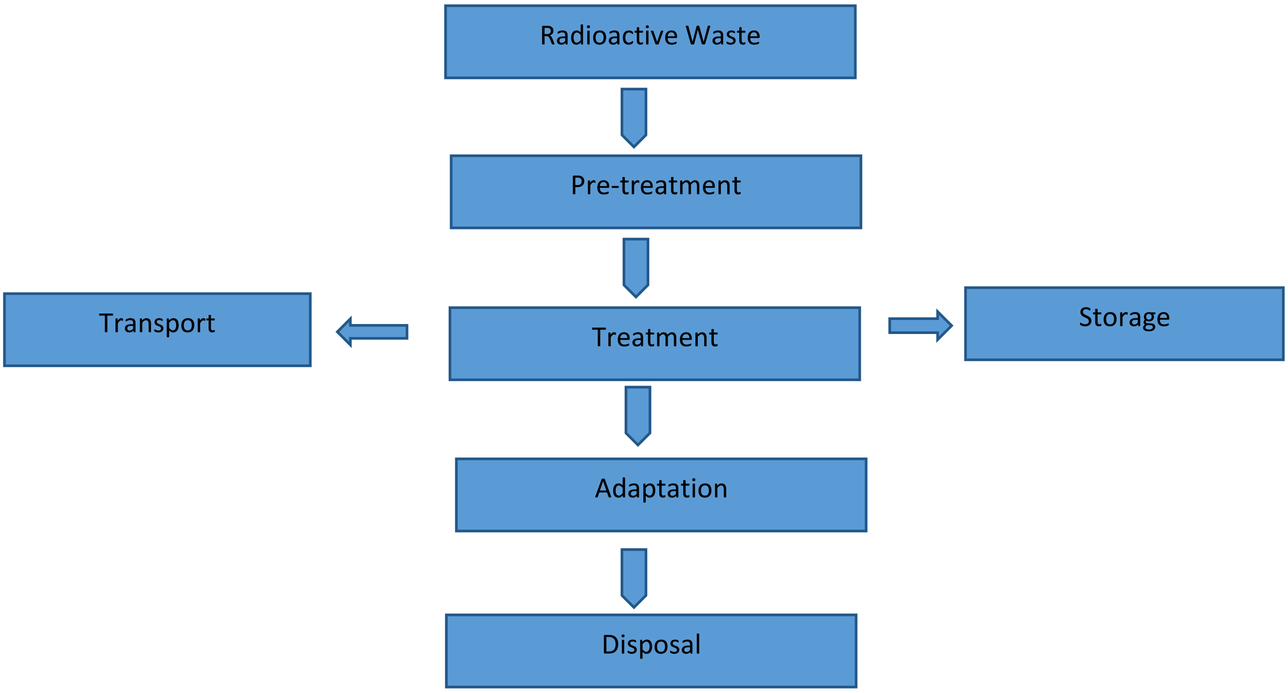

Figure 3. Radioactive Waste Management
Source:(Authors, 2024).

These are wastes with radioactivity levels higher than the activity concentration of very low-level radioactive wastes but are not classified as high-level radioactive wastes. Low and medium-level radioactive wastes are produced as a result of consumables such as plastic boxes, gloves, and filters used in nuclear facilities, as well as dismantling activities of nuclear facilities, or consist of radioactive substances used in industrial non-destructive testing applications and for diagnosis and treatment purposes in medicine.

1. Pre-treatment: In order to prepare radioactive wastes for treatment, the pretreatment step involves processes such as collection, separation, chemical regulation, and decontamination.

2. Treatment: In this step, the volume of radioactive waste is reduced using methods such as ion exchange, incineration, evaporation, precipitation, filtration, and concentration, and the form, content, and properties of the radioactive waste are changed when necessary.

3. Conformity: The transformation of wastes into a form suitable for transportation, storage, and disposal processes, packaging, and, if necessary, preservation with an additional outer package is carried out in the conformity step.

4. Storage: The storage of radioactive waste within a system or facility with the intention of retrieval. Storage can be applied between radioactive waste management steps before disposal.

5. Transportation: Radioactive waste can be transported between radioactive waste management steps before disposal. Radioactive waste is transported in containers specially designed according to its type and can be used during storage and/or disposal as well as transportation.

6. Disposal: Disposal is the final storage of radioactive waste in an appropriate manner without the intention of retrieval. Very low, low and medium level wastes prepared for disposal are sent to surface or near-surface (30 m below the surface) or medium depth (30 to several hundred meters below the surface) disposal facilities for disposal. Today, low and medium-level radioactive waste is safely disposed of in disposal facilities in Germany, America, Sweden, Finland, France, Netherlands, England, Spain, Switzerland, Japan, Canada and many other countries (Özdilek et al., 2006)

Selection of Appropriate Materials for Storage of Nuclear Waste in Türkiye

It is very important to store the wastes of the Mersin Akkuyu Nuclear Power Plants, which are under construction in Türkiye, in appropriate areas in order to create an environment of trust for future generations. Radioactive materials with a half-life of thousands of years should be stored in properly impermeable areas. Approximately 2.5-3 cubic meters of high-level waste is generated annually from a nuclear facility with an average capacity of 1000 MW. According to this calculation, approximately 12-14.5 cubic meters of HLW is generated annually from Akkuyu NPP. Mersin Akkuyu NPP, which has a lifetime of approximately 60 years, needs to gradually transfer the waste generated during its operational life to water pools, interim storage and finally to final storage(Akkuyu, 2024).

The final storage of the waste from the nuclear facility is to ensure that it is stored in the appropriate area based on the radiation permeability properties of the mines that are common and abundant in our country. It is the evaluation of the appropriate material in the light of the studies conducted on the radiation permeability of some mines common in our country (TCCB, 2021).

Alternative Mineral in Nuclear Waste for Sustainable Energy

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Experimental Studies on Monazite Mineral

The most recent studies on monazite were carried out by (Çetiner et al., 2005). and (Stern and Berman, 2001). Although it is stated that all cement-based, pozzolan-based, thermoplastic and organic polymers can be used in the management of radioactive wastes among hazardous wastes, the evaluation of monazite, which exists in nature and can be easily used in radioactive waste management due to its characteristics, is a promising method for the future (Çetiner, 2003). In his doctoral thesis, he determined that neodymium reached the solubility equilibrium constant most efficiently among the solubility equilibrium constants he investigated for lanthanum, neodymium and samarium between 23 and 50 ^{0}C ambient temperatures in a laboratory environment. The results were also found to be consistent with the study conducted by Poitrasson et al., (2004).

Monazite, defined by its monoclinic crystal structure and (Ce, La, Nd, Th) PO_4 chemical formula, is a mineral that generally contains light rare earth elements (REE) and Th. Monazite, which is recommended for the storage of nuclear waste in solid form (in the form of glass and ceramic), has come to the fore with its ability to immobilize radioactive elements and to be sensitive to dissolution at high temperatures. As can be seen from experimental studies conducted in recent years, the solubility of monazite shows a change inversely proportional to temperature (retrograde solubility) in hydrothermal environments (Poitrasson et al., 1996).

Figure 4. Monazite

Informal interviews with converter operators were initially used to collect data. This method was chosen because of its flexibility in obtaining qualitative information about a project. We collected the necessary information through informal conversation. Interviews can provide a much larger amount of information than questionnaires. One of the requirements for applying this technique is that the interviewer has the skills to conduct the process (Gil, 2008).

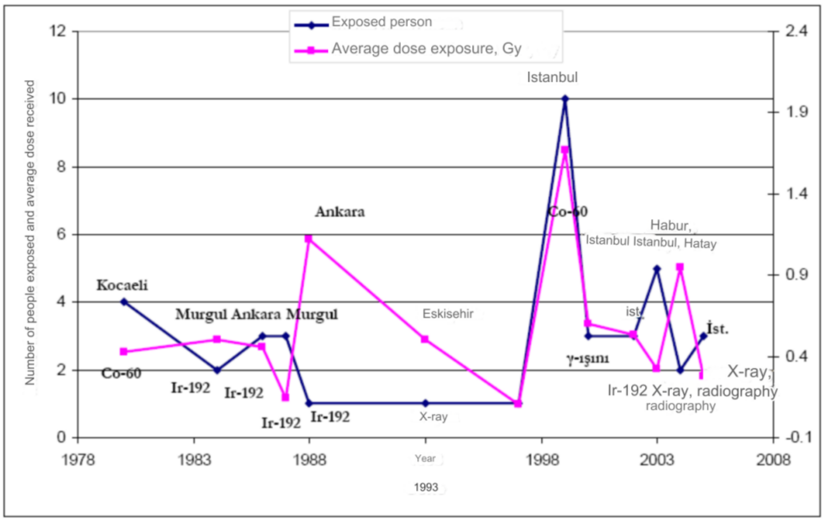
According to Gil (2008), informal interviews are the least structured and are only distinguished from simple conversations because their basic objective is to collect data. They are recommended for exploratory studies, which aim to address realities that are little known to the researcher or to offer an approximate view of the problem being researched. Through interviews, it was possible to understand the main needs and problems mentioned by operators and their impact on their daily work (MTA, 2006).

Nuclear Accidents in the Social Dimension of Sustainable Development (Türkiye Example)

There have been significant differences in the practices of the principles set by the world countries' own nuclear security organizations. After the Three Mile Island (TMI) accident in the USA in 1979, intensive studies were carried out with the participation of various Western countries to determine the measures to be taken at an international level in the event of a nuclear accident. Then, the "Mutual Assistance Principles in Case of Nuclear Accidents and Radiological Hazards" prepared by the IAEA were accepted by 22 countries, including Türkiye. The "Security Series-72" published in 1985 determined the necessary intervention principles for the protection of the public in the event of a nuclear accident.

After the countries affected by the Chernobyl accident were informed of the accident quite late and it was seen that there were significant differences between the countries in the practices, the "Early Notification Agreement in the Event of a Nuclear Accident" and the "Mutual Assistance Agreement in the Event of a Nuclear Accident and Radiological Hazard" were quickly prepared by the IAEA and opened for signature. These agreements determine the principles to be followed in order for other countries to be informed of any accident that occurs in any country as soon as possible, and for these countries to put into effect their previously prepared emergency plans and necessary assistance without delay. The agreements in question were ratified by Türkiye with Law No. 3610 dated 18.1.1990 and entered into force (Amin, 2013). Various nuclear accidents have occurred in Turkey at different times. The events, which are much smaller in scale than the Chernobyl and Three Mile Island incidents mentioned here, are summarized in Figure 6.

Figure 6. Radioactive accidents that occurred in Türkiye between 1980-2005.



Source: (Özdilek and Avşar, 2006).

CONCLUSION

The world is looking for solutions for its rapidly increasing energy needs. Nuclear energy, a different energy source, was used in the world against increasing demands. The high energy it produces per unit has started to attract attention on the way to industrialization. Although it is interesting, its risks have also become quite high. The best way to reduce these risks of nuclear facilities is through proper construction and proper operation. One of the main problems in operation is the disposal of nuclear waste.

Nuclear waste is formed as a result of nuclear energy reactions and other processes in the facility. Nuclear waste continues to radiate for thousands of years and poses a great danger. In order to prevent this danger, after the waste is processed, it is taken to protected special underground storages and its storage is ensured for many years. The storage to be established underground must be resistant to seismic movements, have no underground water, be impermeable and protected.

Nuclear energy has an environmental and social impact area on the way to sustainable development. This powerful energy source has advantages and disadvantages in combating climate change. Nuclear energy, which is an effective tool compared to fossil fuels in reducing greenhouse gases, poses significant risks to both the environment and public health due to radioactive contamination that may occur in the event of a possible accident and nuclear waste generated in energy production. It is possible to face the risk of radioactive contamination while reducing the effects of climate change. Therefore, it seems more rational to prefer energy sources that do not pose serious risks to the environment in combating climate change in terms of ensuring sustainable development.

In this study, the resistance of some minerals found in abundance in Türkiye to radiation was examined and the storage of nuclear waste in these regions was evaluated. From the literature review, it was understood that the Monazite mineral is resistant in this regard. It is suggested that this Monazite, which is found in abundance in our country, can be used in the protection of wastes of planned NPPs in our country.

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