



PROTECTION, SAFETY AND SECURITY REQUIREMENTS FOR URANIUM MINING DEPOSITS IN ROMANIA

Sorin Mihai RADU^{1*}, Ioan I. GÂF-DEAC², Alexandru A. BURIAN³,
Mariana Valentina BOCȘITAN³, Adrian MANOLE³, Ilie IUCAL³

¹ Professor Dr., University of Petrosani, Romania, sorin_mihai_radu@yahoo.com

² Ass. Professor Dr., Romanian Academy, INCE-CEMONT, Bucharest, Romania, smartcityhub.romania@gmail.com

³ University of Petrosani, Romania, Ph.D. Student

DOI: 10.2478/minrv-2026-0055

received – 04.09.2026 / revised – 11.09.2026

accepted – 15.09.2026 / published – 25.09.2026

Abstract: *In the national nuclear chain / cycle, it is not appropriate for protection, safety and security to be separated into complex energy-mining objectives or sub-objectives. Any operational delimitation of them can produce gaps, incompatibilities, even antagonistic situations that do not serve to guarantee the existence and feasible, reliable operation of complex uranium mining systems. The central objective of this article is related to the reporting of the actual protection, safety and security requirements formalized for the underground mining of uranium ores. Derived from this approach, secondary objectives were established such as: the specification of the uranium mining areas on the territory of Romania (the Crucea, Tulgheș and Grințieș mines/ the Bicazul Ardelean area), the "R" Plant and the INCD-CAN Pitesti - Mioveni, in order to justify geographically and geologically, the existence of the completely autochthonous nuclear chain/cycle; links between the nuclear operational space and that of decisions in the protection, safety and security of complex uranium mining objectives. The article presents the requirements in the field of ore extraction from underground uranium mines, the location scenario of the "TG" preparation plant, the uranium-type fuel in the cost of nuclear energy, respectively the articulation, combination and composition of the effective measures in the field.*

Keywords: *energy-mining/uranium complexes, protection, safety and security in uranium mines, plants for the preparation of uranium concentrates*

1. Introduction

On a local / national and international level, there are concerns for the study of feasibility, protection, safety and security in the exploitation of uranium deposits.

In Romania, attention is focused on how targets such as the Tulgheș-Harghita and Grințieș-Neamț uranium mines are designed and put into operation from the perspective of the original, new approach to the protection, safety and security of these complex investments.

It is intended to highlight the modern and safe technological character of the exploitation and the expansion of the impact on the Romanian and European energy system from the perspective of the energy security of Romania and the EU, the environment, flexibility and technological sustainability, with the possibility of generalization on a global level this type of industrial activity.

Through this scientific approach, researchers, designers, builders and practitioners are offered a complex, integrated, new set of protection, safety and security against incidents/accidents, radioactivity, the health of employees and communities, in an integrated vision, starting from mining, the transport of the ore, the processing to make uranium concentrates, the obtaining of fuel in bundles, the operationalization in the core of the reactors of the uranium fuel through the fission process and the management of radioactive waste.

In Romania and globally, there are multiple nuclear protection, safety and security provisions, distinct and separate, which in various cases are inconsistent, excessive or non-comprehensive, which calls for their integrated, complex, united, articulated or combined approach for efficiency and relevance.

* Corresponding author: Sorin Mihai Radu, Professor Eng. Ph.D, University of Petrosani, Romania, sorin_mihai_radu@yahoo.com

As such, it is necessary to create the integrated legislative framework for protection, safety and security, targeting the entire integrated nuclear cycle (chain) from uranium mining to radioactive waste management.

The development of this research required field studies, observations, analyzes and comparisons at the Tulgeş - Grinţieş mines, the "R" Plant from Feldioara, INCD Pitesti, institutions and authorities in the field.

2. Methods, study methodology

2.1. Regarding the protection, safety and security requirements of uranium mining

From the research of situations in the field it was deduced that the perception of risk and nuclear consequences are present for uranium mining units because they resort to DMDU (*Decision Making under Deep Uncertainty*), evaluating the probability of success of the production scenarios in question.

Irradiation occurs when various materials (mines, from underground deposits) receive, receive ionizing radiation.

Contamination occurs when radioactive particles enter or deposit on a living organism or material surface.

Radioactivity is the potential of substances, including uranium ores, to develop energy-bearing alpha (helium nuclei), beta (electrons) or gamma (X-ray photons) radiation by decay. (fig. 1)

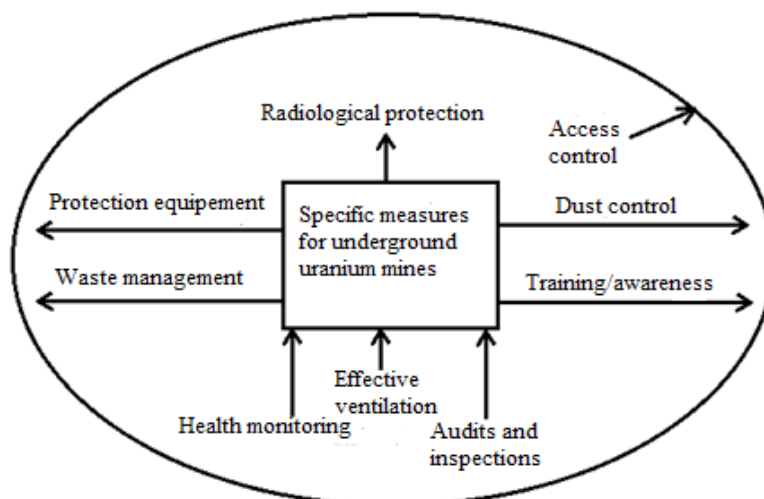


Fig. 1 Specific measures for underground mining of uranium ores

Radioactive decay is evidenced in naturally occurring radioactive elements, and natural radioactivity is related to the series ^{238}U as well as that of thorium with series ^{238}Th ($1.39 \cdot 10^{10}$ years).

Series ^{238}U ($7.1 \cdot 10^8$ years) determine the isotope of lead ^{207}Pb , and among the radioactive isotopes are mentioned: ^{40}K (0.012%; $1.2 \cdot 10^9$ years; beta; CE); ^{87}Rb (27.8%; $6.2 \cdot 10^{10}$ years; beta); ^{147}Sm (15.1%; $1.3 \cdot 10^{11}$ years; alpha); ^{115}In (95.8%; $6.0 \cdot 10^{14}$ years; beta), ^{190}Pt (0.012%; 10^{12} years; alpha).

So, radioactivity is the result of the disintegration of atoms, of nuclei; an isotope that has undergone decay becomes radioactive.

It should be emphasized that by disintegration (subatomic particles/high energy electromagnetic waves) a radioactive substance never disappears completely.

Uranium ^{238}U has a half-life of 4.5 million years through the emission of alpha rays (α).

The number of disintegrations in one second gives the named unit of measure becquerel (Bq).

Artificial radioactivity is obtained by bombardment with charged particles.

Fusion is the basis for obtaining nuclear energy in the future, by absorbing neutrons from large atomic nuclei (uranium).

Currently, heat is generated in the reactor by the disintegration of radioactive uranium atoms - ^{235}U .

Radioactive pollution (radiotoxicity) is generated by elements as follows: ^{90}Sr , ^{226}Ra , ^{210}Po , ^{239}Pu (very big), ^{45}Ca , ^{89}Sr , ^{140}Ba , ^{131}I , U natural (large), ^{24}Na , ^{32}P , ^{60}Co , ^{82}Br , ^{204}Tl , ^{22}Na , ^{42}K , ^{55}Fe (average), ^3H , ^{14}C , ^{51}Cr , ^{201}Tl (small).

The minimum dose of global irradiation of the body is below 20 Rem, and above 700 Rem the effect is lethal.

In the present case, the natural uranium exploited in Romania contains a mixture of isotopes found in nature, the depleted uranium has isotope ^{235}U below the size found in nature, and the enriched uranium has isotope ^{235}U or ^{233}U higher than the ratio between isotopes ^{235}U and ^{238}U in natural uranium (0.71%).

Special fissile materials are plutonium 239, uranium 233 and enriched uranium. Mainly, in Romania 4 underground uranium mining zones are identified. (fig. 2)



Fig. 2 Branches of the National Uranium Company in Romania
(Source: adapted from CNE Cernavodă, 2023)

In Romania, a General Management System is maintained according to Law no. 111/1996 regarding the safe conduct, regulation, authorization and control of nuclear activities.

The Integrated Management System at CNE Cernavodă refers to nuclear safety requirements through the ISO 14001 / ISO 45001 standards.

3. Results, discussion

3.1. Regarding the requirements in the field of extraction of ores from underground uranium mines

Nuclearelectrica (SNN) owns all the units for an integrated nuclear cycle: from the extraction of uranium ore from the Tulgheș (Harghita) - Grințieș (Neamț) deposit, the "R" Feldioara uranium concentrate plant, the Pitesti nuclear fuel plant to electricity production in the Cernavodă nuclear power plant.

The "R" plant is located 10 kilometers from the town of Feldioara, in a forest area. (fig. 3; fig. 4)



Fig. 3 Complex "R" Feldioara uranium ore concentration plant
(Source: processing-adaptation from the research portfolio, 2023)



Fig. 4 Geographical location of the "R" Plant (Feldioara) of uranium ore concentration
(Source: Link to the source (maps.com), 2023)

At the "R" Plant (fig. 3) there are systems for the conversion of uranium ore concentrates into UO_3 and the installations for the production and concentration of heavy water, deuterium or deuterium compounds (at Halânga - Turnu Severin) are based on the exchanges of water-hydrogen sulfide or ammonia-hydrogen.

In Romania, concentrated uranium ("yellow cake") is produced by processing the ore, which has approx. 0.1% uranium.

For the operation of 1000 MWe at a large reactor, approx. 200 t/year, and uranium hexafluoride enriches the uranium fuel.

Further, the metal uranium dioxide appears and especially plutonium dioxide (fissile metal), resulting from the "burnt" fuel, which is used to make atomic bombs.

Normally, in order to ensure energy independence, the closure of the nuclear cycle is aimed at, it is also necessary to consider the closure of the protection, safety and security cycle (unification, articulation, combination, composition of the measures in question). (fig. 5)

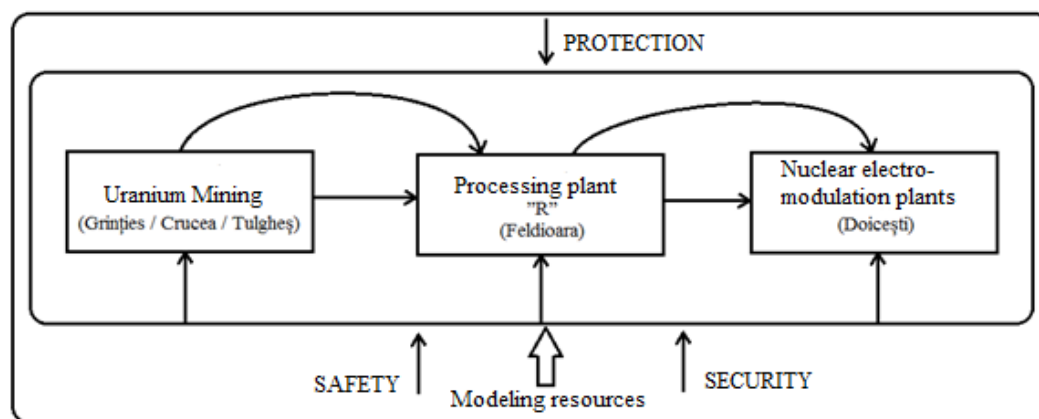


Fig. 5 Protection, safety and security on the entire uranium chain/cycle in Romania

The only deposit currently in operation is the one from Crucea (Suceava), which is being depleted.

Uranium demand will increase in the next period, to the equivalent of 112,000 metric tons.

The share of nuclear fuel in the cost of energy is approx. 16%, of which uranium effectively 5-6%.

Uranium mining activity is carried out according to the Mining Law no. 85/2003 and the Application Norms by H.G. no. 1208/2003.

Referring to the SWOT analysis of the uranium resources in Romania, [1], (fig. 6) the following is highlighted:

- **Strong points:** the "open" cycle of the radioactive fuel; the existence of domestic research and design; advanced knowledge and practice in complementary industrial sectors; technology focused on natural uranium, the existence of uranium ore deposits in the country.

- **Weaknesses:** high costs in underground mining of uranium ore, used mining technologies; restructuring requirements (removal of subsidies from the national public budget), upgrading of the mining exploitation system and processing of ore into concentrates; high costs for mining new uranium ore deposits; supplementary import of uranium octoxide from external sources.

- **Opportunities:** integrated projects for mine opening of deposits and ore preparation, processing, refining; the use of imported uranium, new installations with high-performance technologies; local production of uranium concentrates; further investments for units 3 and 4 in Cernavodă.

- **Risks:** high capital costs for the 2 new nuclear reactors; limited financial resources for investments and the environment; the international variation of the uranium price; limited domestic mining reserves.

From a geological point of view, the Romanian uranium deposits (Tugheș, Grințies) are concentrated in Permian sandstones in the upper zone of the Terrigen-Continental Paleozoic series, in the Saxonian. [2]

The formations, as a rule, are calcareous from the Jurassic and the Lower Cretaceous, being noted flaps belonging to the terrigenous Senonian.

The uranium deposits were formed through an exogenous-epigenetic process, the solid bitumen being from the Triassic.

Ore lenses, due to disjunctive tectonics, are fractured, being a Hercynian tectonic cycle.

Uraninite (UO_2) has 75-90% uranium, and in hydrothermal veins under 0.25% ThO_2 .

It is specified that in Romania the maximum uranium concentration allowed in mine waters is 0.021 mg/dm^3 (0.25 mg/dm^3 in Canada, 0.3 mg/dm^3 in Germany and 1.8 mg/dm^3 in France); so this parameter is much more restrictive on a national level.

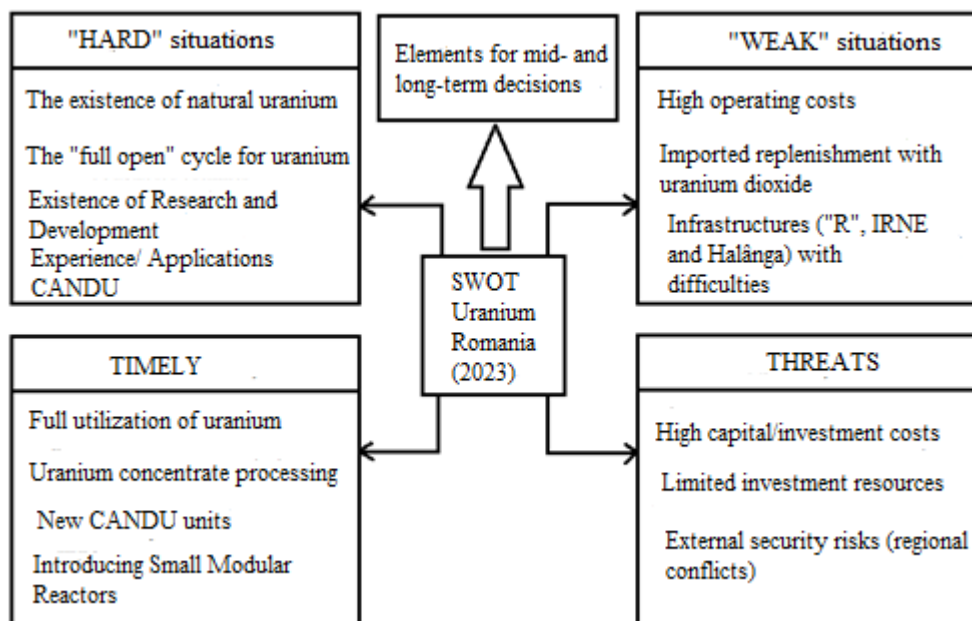


Fig. 6. SWOT for Uranium in Romania (2023) in accordance with Romania's mining strategy (2017-2035)

At Tulgheș and Grințieș, the reduction of mine water radioactivity can be achieved by: 1) ion exchange, 2) co-precipitation, 3) biological reduction.

The uranium resources in Romania are exploited at costs of over 130 dollars/kg of uranium.

The geological potential shows that there are 3,100 t of proven, immediate resources and 3,600 t of explored, outlined resources.

Also, the resources under prospecting (discovery) are another 6,000 t, of which 3,000 t are considered forecasted, certain resources.

The Tulgheș-Grințieș deposit has a geological potential of 6,000 t of uranium. The share of geophysical activity worldwide is 34.84% for ores, including uranium deposits in Romania. [3]

The general scheme for the exploitation of uranium deposits in Romania aims at the presence of this useful mineral substance both underground (in the massif of rocks, deposit and extraction pits) and on the surface (preparation plants, concentration, heaps).

A first general observation is that the uranium mining extractive sector itself is really complex, in "confrontation" with nature / environment (surface and underground), with considerable investment expenses, and mining projects have a long processing time to be put into operation, with significant risk measures.

Moreover, characteristic of the field is the fact that the geo-mining investment made is "consumed" simultaneously with exploitation.

Therefore, continuous "maintenance of production capacity" investigations are required as a deposit / portion of the deposit is depleted with uranium extraction.

Following the optimization of the technological variants of slaughtering through modeling, we find that, once they have been generated, they are evaluated according to the type, form and content of the functions that delimit, define one or another result indicator (commandable values).

In essence, the multidirectional, including multicriteria approach to the issue under consideration is all-encompassing.

3.2. The scenario of the location of the preparation plant "TG"

The investment objectives related to the new uranium deposit Tugheș - Grințieș in the Eastern Carpathians have the complementary requirement to review the capacity of the "R" Plant from Feldioara, to replace it (extension, modernization and re-technology of the "R" Plant) for the additional processing of 80,000 – 120,000 tons/year of uranium ore.

As such, the new investment called the "TG" uranium ore preparation plant is being considered, which has as its main technological operations:

1) *granulometric preparation*: crushing and volumetric sorting; mono and multi-stage schemes are provided in open or closed circuits, grinding with a semi-autogenous ball mill, symptotic classification in hydrocyclones, followed by thickening of the slurry with the help of the radial thickener;

2) *hydrometallurgical extraction of uranium*: dynamic and static chemical leaching, separation of the solid-liquid phases, further separation with ion-exchange resins, with organic solvents and precipitation, so that finally the desiccation, drying, calcination, packaging of the uranium concentrate takes place for delivery;

3) *management of the preparation tailings* by thickening, recirculating the water, and sending it to the settling pond.

The scenario for the location of the "TG" preparation plant refers, in this context, to the location next to the current Plant, respectively the complementary production of uranium concentrates in the possible extended and refurbished structure of the "R" Plant in the Feldioara perimeter, using the current utility network and the already validated protection, safety and security potential existing in the area.

In fact, this will be the only national supplier of sinterable uranium dioxide powder, material for the nuclear fuel of the Cernavodă plant and the Doicești-Dâmbovița SMR, given that the Crucea-Botusana field is going into exhaustion/liquidation.

The "TG" plant will be a modular structure, having crushing, grinding, symptotic classification, thickening, secondary and tertiary crushing, dynamic and bulk leaching, settling and filtration, extraction with ion exchange resins, with organic solvents, precipitation and drying, waste management.

The established radiation protection area will be 17.3 ha, in which poor uranium ore ground below 100 μm will be processed, approximately 700-750 t of uranium concentrates will be obtained.

The research of the deposit (preliminary and detailed mining exploration) was started in the Grințieș area as early as 1963, and in Crucea - Suceava it started in 1965.

In 1997, the Crucea – Suceava mine was separated from the Grințieș mine.

At Grințieș, the uranium ore mining capacity reaches 124,000 t/year.

The uranium accumulation at Grințieș is classified as the most significant deposit in the field in Romania. (fig. 7).



Fig. 7. The location of the Grințieș uranium mining area in Romania, on the surface of Neamț County and in relation to the distances from the main cities in the territory
(Source: according to specialized information, 2023)

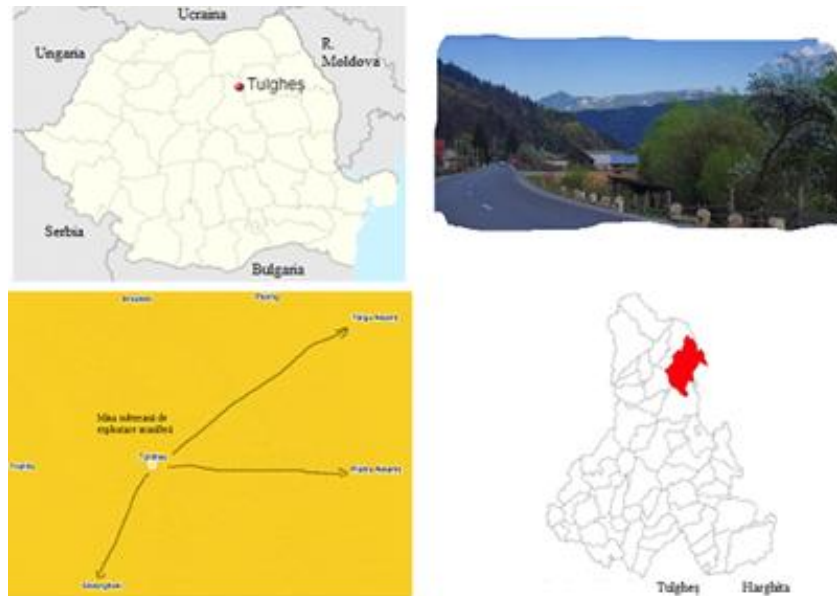
The Grințieș mine had 10 exploration/experimental galleries in the Prisecani underground mining perimeter, 27 at Primatar and 6 at Pintec.

The uranium ore was experimentally sent to the "R" Plant in Feldioara, from where the refined product reaches IRNE Pitesti, for the bars/bundles needed at CNE Cernavodă.

The Piatra-Neamț Environmental Radioactivity Monitoring Station annually takes samples of surface and underground water, soil and vegetation from the perimeters of Bicașu Ardelean – Telec and Tulgheș – Grințieș, where mining activities of exploration and exploitation of uranium accumulations are expected, and the radioactivity is analyzed global beta, respectively gamma-spectrometry and local and regional radiochemistry.

The results (in 2022) show for the Primatar stream the value of 228.6 Bq/m³ and for the Bicaș river 263.2 Bq/m³.

A mining area of uranium interest is Tulgheș-Harghita, which enters for exploitation in parallel with the Grințieș-Neamț deposit. (fig. 8).



*Fig. 8 The location of the Tulgheș uranium mining area in Romania, on the surface of Harghita county and in relation to the distances from the main cities in the territory
(Source: according to specialized information, 2023)*

On the territory of Romania, there are also other uranium locations, among which (older or newer, closed, under conservation, refurbished or exhausted/liquidated) we can mention: the Crucea uranium mine, the Băița mine, the Iulia mine - Puțul 3, the area former thorium mines, tailings from uranium ore, the mining area/ Colonia Ciudanovița, the Oravița mining operation, the uranium mines of Dobrei Nord, Dobrei sud, Natra, the Ștei - Bihor area, etc.

As for the continuation of the nuclear cycle on the territory of Romania, it is located at INCDN Pitesti (Mioveni)-Argeș, a segment where protection, safety and security are as intensive as at large nuclear power plants, respectively at underground uranium mines.

At the Pitești-Mioveni Nuclear Research Institute, the manufacturing of fuel elements for nuclear reactors (sealed sheaths, beams or rods, instruments for commanding or monitoring the reprocessing of natural uranium, depleted uranium and fissile materials in particular) is used, specific nuclear installations are found.

Here, multiple use technologies are often researched, according to the legislation in force. [4]

At the plants/laboratories from Pitesti-Mioveni, cryptography is frequently used, which includes the principles, means and methods to hide the information content of the data, to protect their undetectable, unauthorized modification, resorting to secrecy parameters, management of coding keys regarding nuclear activities strictly according to the legislation in force.

3.3. Links between the uranium operational space and that of the decisions in protecting complex energy-nuclear systems

From the field research carried out in the uranium-bearing areas in Romania, consulting the related documentation and having discussions with the decision-makers and beneficiaries of the energy complexes, it was deduced that there is a real connection, independence and correlation between the operational uranium-bearing space and that of the decisions in protecting the nuclear-electrical systems complex. (fig. 9)

At the same time, the recommendation to optimize the operational space and that of the decisions in protecting complex nuclear-electrical systems is advanced.

Overall, technologies and especially emerging strategies have the potential to improve the protection of nuclear materials, devices, facilities and information. [5]

In addition, Artificial Intelligence (AI), remote sensing allows real-time data analysis, detecting unauthorized access to large energy-mining targets, including reporting activities considered suspicious in the area.

In this context, the protection of the exploitable uranium perimeter is decisive for preventing and stopping unauthorized access to the nuclear energy locations.

Nuclear reactors are the infrastructures of the clean energy system, so they are ready for long-term operation, but their life cycle must be optimized from the perspective of continuing to ensure their security. [6]

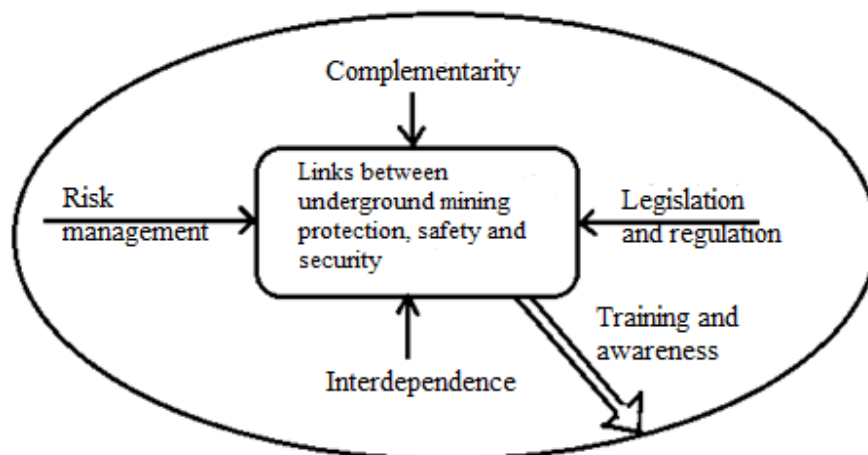


Fig. 9 Links between protection, safety and security in mines of underground extraction of uranium ore

At the same time, it is important to evaluate the vulnerabilities for all tangible and intangible uranium assets, using the interconnected devices, the different connection methods, the architectures and the protocols established for the field in question.

As such, the recommendation is advanced to create a critical platform required for the handling and management of useful high-resolution data in nuclear process control.

Typically, continuous, detailed analysis of potential vulnerability incidents in complex energy-mining targets, including uranium mines, must be carried out.

At the same time, the proposal for real-time control-evaluation of temperature, pressure, flow variables is advanced; they are sent to the operator for monitoring and control.

Equally, continuous analysis of human subjective vulnerability is required to avoid erroneous mining operations, which could create new vulnerabilities and internal threats in uranium mines.

Basically, the potential to generate the optimal protection, safety and security strategy against incidents/accidents with consequences in uranium mining must be established.

It is currently observed that, in fact, the costs of protection, safety and security of underground uranium mining infrastructures (in other words, of complex energy-mining objectives) increase during their life cycle, as new threats, deficiencies in respective perimeters. [7]

Through the present research, the thesis is advanced that the relationship between general safety, national safety and the protection, safety and security of complex energy-mining objectives (uranium mines) has a direct, interconnected relationship.

As such, the integral, holistic approach to the field proves useful, but the intervention must be gradual, respond directly to risks, risk classification processes, integration of qualitative and quantitative assessments. [8]

On this basis, it is proposed to establish an integrated framework applicable to quasi-totality of situations and those that are operationalizing complex energy-mining objectives, respectively the exploitation of uranium ores, using an inventory of integrated methods and devices, instruments according to risk, noting technical deviations, linking results to organizational factors, general safety and national security.

4. Conclusions

– The finding that any nuclear energy program depends on the nuclear cycle, from uranium mining to the storage of radioactive waste, is shown. As such, a representative scheme regarding specific protection, safety and security measures for underground uranium mining mines is needed on top management's agenda.

– Although numerous data, information and knowledge about nuclear locations and activities have a reserved character (a certain level of service secrecy), however, in the context the location of the uranium extraction mines (Crucea, Tulgheș, Grințieș), the Uzina de preparation-concentration "R" from Feldioara, Institute of Nuclear Research Pitesti - Mioveni, these being complex energy-mining objectives entered under the scope of protection, safety and security in the field.

– It is concluded, for the first time, that the problem of improving protection, safety and security is important to be addressed throughout the uranium chain in Romania. Moreover, this is the essential contribution and proposition revealed in the present research.

– It is stated that the share of fuel in the cost of nuclear energy is approx. 16%, of which for the actual uranium the level reaches 5-6%. The uranium fuel in Romania costs approx. 130 US dollars/kg of uranium. On a national level, we find that natural uranium resources (deposits, geological deposits with ore) provide what is needed for consumption in complex energy-nuclear objectives.

– In order to ensure the energy requirement of the market, it is recommended to close the domestic nuclear cycle; in parallel, it is necessary to take into account the closing of the cycle of protection, safety and security by articulating, combining and composing the effective measures in the field.

References

- [1] * * *, 2017
Mining Strategy of Romania 2017 – 2035, Bucharest
- [2] **Traistă E. Ionică, M.**, 2026
Radioactivity of mine waters from uranium mines and its reduction. The impact of mining activity on the environment, AGIR Bulletin, pp.58 – 62, Bucharest, no. 3/2006
- [3] **Ianas M.**, 2012
Geophysical research of ores, 17th Symposium on earth physics and applied geophysics, Prospecciones S.A., Bucharest
- [4] * * *, 2000
List of dual-use products and technologies, Art. 3, Regulation (EC) no. 1334/2000
- [5] **Shubayr N.**, 2024
Nuclear security measures: A review of selected emerging technologies and strategies, Journal of Radiation Research and Applied Sciences, Volume 17, Issue 1, ISSN 1687-8507, doi.org/10.1016/j.jrras.2023.100814
- [6] **Abiodun Ayodeji A., et al.**, 2023
Cyber security in the nuclear industry: A closer look at digital control systems, networks and human factors, Progress in Nuclear Energy, Volume 161, ISSN 0149-1970
- [7] **Scott N., Prashant J., Huning Al.**, 2023
Oak Ridge National Laboratory Security by Design: A Plant Design and Component-Based Approach to Technical Solutions to Insider and Outsider Threat. US: N. p
- [8] **Immonen E.**, 2023
Graded approach to nuclear safety - State of the practice. VTT Technical Research Centre of Finland. VTT Research Report



This article is an open access article distributed under the Creative Commons BY SA 4.0 license. Authors retain all copyrights and agree to the terms of the above-mentioned CC BY SA 4.0 license.