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An Integrated Framework for Dynamic Risk Assessment and Decision Making for Reactor Safety

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ABSTRACT

Some critical and hazardous facilities such as nuclear power plants, oil and gas production sites, and hazardous materials storage sites provide benefits to society, but are inherently risky. Failure of these systems has an increased criticality for its adverse effects on the ecological system and human health. Therefore, the nuclear safety process aims to safeguard individuals and the surrounding medium from radiation risks by considering a restricted risk assessment framework along with a safety analysis plan that leads to rapid decision-making. By such a framework, the facilities' activities justification, optimization of protection, individuals' risk limitation, accident prevention, and emergency preparedness and response can be addressed. The diversity in risk assessment approaches is such that there are many methods for any industry. Research reactors are deemed manifold-roles environments that perform the various tasking of training, research, and commercial goals. And this is even though it contains risks and possible sources of harm. Therefore, reactor managers have to make accurate and appropriate decisions at the right time, based on little available knowledge. Few articles review this hazardous environment and industries' risks as well as human and environmental consequences and how can ensure human control in these critical environments. Since the beginning of the research reactors, operation Decisions concerning planning and management have represented a major concern for decision-makers in this field. International organizations (IAEA Safety Principles, 2006 & IAEA, 2007) have identified the importance of accurate planning and the Fundamental Safety Principles which are necessary and critical to the operation of nuclear facilities, dealing with human resources, supplies, and materials, as well as to radioisotope produce requested, training and, research constraints. In this research, a framework is proposed for combining IAEA Safety Principles and Risk Assessment process for helping manage risks, making decisions, determine and achieving goals, and perfecting performance for these critical facilities. The neural network can be subjected to verdict the priorities risks and to calculate the weight factors that must be taken into account in the decision- making process. For Clarification of the proposed framework performance the case study was conducted on a real-world for Research Reactor.

1. INTRODUCTION

Human business and tasks and surrounding nature are considered as are potential sources of risks and hazards. The concept 'risk' Indicates that injury to human and the surrounding medium requires to be considered both in from were of both the severity of the potential harm and its likelihood. Safety is accomplished by guaranteeing that hazards are preserved as low as reasonably practicable (ALARP). According the ALARP term, measures to decrease risks should be executed if there is an aggregate inequality among the reachable grade of risk detraction and the attempts necessary to decrease it. In most countries of the world there are the safety,

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security, and regulations and Guarantees, policies, and targets that determine the fundamentals for the designing and working of their Reactors and nuclear facilities. The main purpose of applied these goals are to bring down radiation exposures from regular operations and to prevent, with more confidence, incidents from happening at nuclear facilities. Another purpose is to alleviate consequences in case an incident should happen. Nuclear energy form a modern covenant in the history of human energy field and developments, and it has been greatly utilized in most countries of the world. But regrettably, in the history of nuclear energy field three dangerous nuclear incidents occurred. The study and evolution of reliable and safe nuclear energy systems are imperious, That's because nuclear safety is an essential issue for the field of nuclear energy, Nuclear energy should also be developed based on learning from the dangerous accidents that occurred in history [1]. Until now, persistent attempts are as yet now made by the nuclear community to ameliorate the nuclear power systems' safety and, competence. To fulfill this amelioration, the physical nature, and state of the nuclear reactor has to be precisely and clearly enough specified and examined as the basis follow in new reactor planning and design. [2].

The likelihood of undesired outcomes in Working on the nuclear facilities must be extremely less than the risks related to other industrial fields indeed agreeable. Thus, appropriate decisions related to nuclear safety can be anticipated, studied, and examined highly extent. Till now,It is mainly fundamentally on the Deterministic Safety Assessment (DSA) in decision-making process that very often followes,even can achieve a elevated level of safety can be achieved by defining a set of rules and restrictions. However, the deterministic rules and requirements are often extremely overrated and do not take into regard the likelihood of system failure. Therefore, the novel method of decision-making is centered integrating for outcomes obtained as autputs from process of Deterministic Safety Assessment (DSA) and Probabilistic Safety Assessment (PSA). However, the critical and complex decisions on nuclear facilities which have a changing nature demand very a lot of inputs, for example protection, economic indicators, uncertainty, and so what. observance of such a broad set of factors is represent a complex multi-attribute process for taking into account of such a wide range of factors is needed to more effort that's because of the complex, and multi-features of the process. Therefore, a framework of Integrated Risk Informed Decision Making (IRIDM) has been evolved to overcome this challenge. IRIDM is a structural process it has a set of inputs that are evaluated and taken into account with various types of risk corresponding to it. However, the assessment of the input is based in general on the personal judgments for the decision-makers, Unfortunately there is not available generally utilized methodology on how to deal with this problem [3]. Even can utilize research reactors and use in a diversity of scientific, training research, and production purposes this needs to be designed distinctly and running in a certain way, Hence, there is an additional burden on the system to achieve and applied safety procedures. May find that research reactors are tiny and Containing less stocking of radionuclides and fuel in comparison to power reactors although that, It has a greater number of accidents that Possibly will occur. With the presence of nuclear facilities in areas full of the population in addition to The lack of containment buildings and high burnup cores, the worldwide interest in risk and safety assessment of these critical systems[4]. The international atomic energy agency (IAEA) In 2008, issued safety report for a research reactors. The purpose of this was to provide operators, decision-makers, and the organization responsible for reactor management with procedures and methods for assessment risks for reactor and analyzing the radiological effects of incidents for the research reactors. The International Atomic Energy Agency defined a nuclear and radiation accident as an event that Causing to the emission of radiation and leads to significant effects on people, the environment, or the Enterprise. Within such an incident involving a nuclear reactor, the reactor core is a crucial component that when spoilage, will cause the emission of significant amounts of radionuclides. Thus the IAEA role is only the issuance of generic safety standards and indicators that provide the help for national authority and adopted through it as the regulatory body is accountable for applied the nuclear law in the country [5]. IAEA has set up the essential 24 principles for recommended safety assessment inclusive of its objective, domain, uses, and procedures [6].

The Problem Definition: It is not possible to rely only on the IRIDM process to make the right decision at the right time for nuclear facilities; this is because it has some flaws and limitations that appear when dealing with critical applications and areas. For example:

1- The decision-making process usually includes uncertainties associated with the system status choices and present components. Therefore, evaluation and assessment steps will needed taking into account various parameters of a system for an improved decision-making process.

2- the IRIDM Process Relies on people to prioritize risks and factors that must be consideration in the decision-making process, for the IRIDM process to be reliable, there should be no prejudice in the final decision.

3- To make the appropriate decision, information and assessments of potential risks and prioritization are needed, along with deterministic studies.

4- IRIDM does not depend on the decision-making process on the variables that occur in the work environment, which makes the decision-making process frozen and inappropriate for events.

5- Critical and complex facilities contain many overlapping factors that have different shapes and different weights according to the problem under consideration and therefore need documentation, review, measurement, and communication to achieve the right decisions, IRIDM is only not adequate.

This work aims to present the improved framework for the decision-making process for achieving higher accuracy to ensure the safety of nuclear reactors. Risk assessment process with IAEA regulations in the decision-making process on achieving higher accuracy in the decision-making process to ensure the safety of nuclear reactors. the main contribution of this work demonstrates that the integration of operational experience, probability considerations, standards, and international regulations, taking into account the uncertainty in nuclear facilities and other environmental factors, is capable of achieving safety and ensuring coherent and balanced decision-making.

2. THE PROPOSED INTEGRATED FRAMEWORK FOR DYNAMIC RISK ASSESSMENT AND DECISION MAKING

2.1 Key Aspect of Integrated Risk Informed Decision Making (IRIDM) Strategy

The IRIDM process can be primarily specified in a recent, as its methodical approach aims to determine and stable integration for the main Participants affecting nuclear facility safety. And despite that, the universality of the IRIDM technique makes its application appropriate for all kinds of organizations and nuclear facilities that redound increase in radiation hazardous, Which include nuclear plants as well as the management of radioactive waste, the utilize of radiation and radioactive sources, and the transport of radioactive material Moreover, the IRIDM process has been characterized by it an elastic tool, which can suitably be modified, can be coming out well applied to the technological non-nuclear facilities [7, 8].

2.2 Basic framework and key elements of IRIDM

The main elements of the IRIDM process are illustrated in Fig.2.some or all of these elements should be evaluated relay on the nature and objective of the decision, and the timetable in which the decision has to be reached. It is clear, the more information available that is taken into account is sufficiently large, the best the decision is probable to be in achieving the overall targets. None of these elements is new but it is the process of integrating them in a systematic method that has a new practice. [9]. The significance of each element in IRIDM process is contingent on the decision to be made; with the variation of the problem, the relativity significance of each element may also vary. Having assessed the significance of each element and thought about carefully the possible safety measures, the decision taken must achieve a balance between different considerations. An initial decision should be Vivificated by repeating the process to guarantee that all safety requirements are achieved. When this has been completed, the selected safety measures can be performed. However, this should not be the end of the process, but the performed decision should be tracked and monitored, and corrective steps should be taken, If there is a need for it, to ensure that the decision has achieved the wanted outcome.

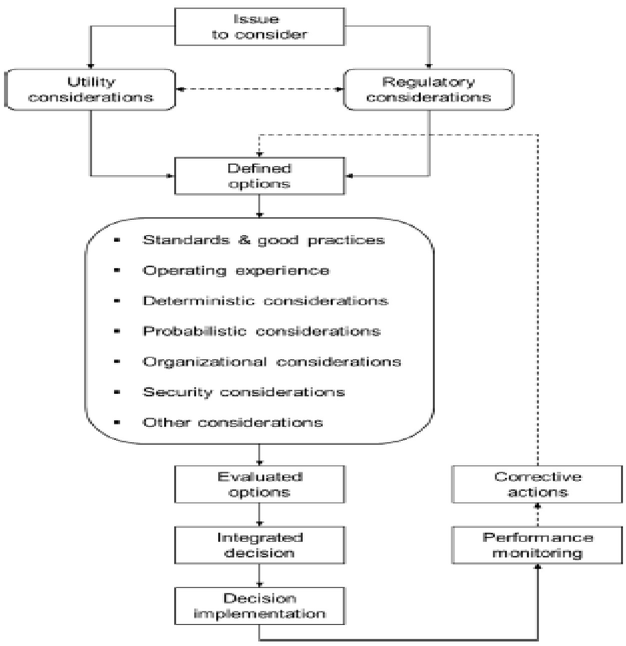

Fig. (1): IRIDM framework and key elements

2.3 Uncertainty assessment in the IRIDM process

The uncertainties of the numerical outcomes of analyses, deterministic and probabilistic, are affected by presumptions, border conditions, the availability of authoritative data, and other conditions and limitations. Uncertainties could also be influenced by natural phenomena, age, expert verdicts, and analytical models. Also, In addition, the more extra qualitative inputs will have uncertainties related to them, back it in part by how they have been concluded. Taking account of these factors extremely reinforces the validity of any decision produced through the IRIDM process. The best way to be dealt with uncertainties that it is should to be a part of the IRIDM reporting structure. Several of the dangerous unusual observations and events that have taken place were not forecasted by present analyses. It is thus substantial to recognize and understand the uncertainties produced by the incompleteness of the risk framework. Thus, through the IRIDM running, suitable concentration and attention to the various kinds of uncertainties should be given in the analysis and interpretation of the results. Therefore, when using IRIDM approach should implicate applying a program of monitoring, feedback, and eventual corrective procedures [6].

2.4 The proposed integrated framework

Figure 3 depicts the Proposed Integrated framework that we develop to avoid limitations in using the IRIDM framework. This framework is a complete life cycle information management model for nuclear reactors consisting of IRIDIM process and Risk Assessment process. The framework consists of a three-layer model that describes the integration between basic steps in Risk assessment, integrated risk-informed decision-making (IRIDM) process, and IAEA regulations and standards organizing for the nuclear facility. One major target of nuclear safety is to safeguard the public and the surroundings from the hazards and Consequences of using ionizing radiation. And that is the motivation why The IAEA has promulgated and publicized essential rules and principles that aims to the consideration of sources of risks and the information available about its analysis In addition to deterministic safety analysis. This process can be appropriately carried out using an (IRIDM) framework. In special, the Fundamental Safety Principles [1] can count on IRIDM process in the special part of processing legal authority, leadership and management for safety, optimization of safeguards, reduction of risks to individuals, protection of incidents, and emergency preparation and response. to make decisions in an IRIDM framework The outcomes of the safety assessment have to be used, out of which the insights and outcomes from the deterministic and probabilistic assessments and any other requirements are joint in making decisions on safety issues related to the facility or activities. It is not potential to depend only on deterministic assessments in the decision-making process because it relays on all events out of the will. The organizations risk and factors are multiple, complex, and intertwined and need to be measured, evaluated, and prioritized, and very dangerous to facilitate the decision-making process. Therefore, we find that the international regulations and principles issued by the IAEA are unable to deal with the complex nature of nuclear facilities, in addition to the continuous changes in the work environment. Hence appeared the necessity and importance of applying the special steps of the Risk assessment process to improve the decision-making process enough to identify the optimum solution.

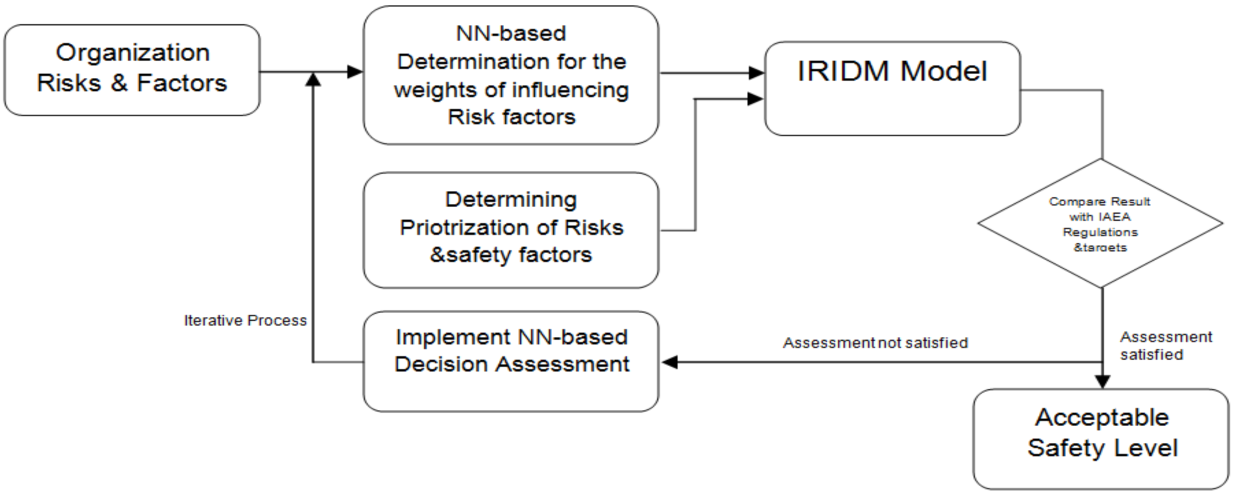

Fig. (4): the Proposed Integrated Framework for Dynamic Risk Assessment and Decision-Making for Reactor Safety

Step 1: Selection of driving Risks and factors

Deterministic Inputs: Usually, the Deterministic Safety Assessment (DSA) has the biggest effect on decision-making process. The deterministic inputs lid a group of values, dubs decisive standards and the efficiency of carrying out in the nuclear facility, which corresponds to with which its safety is accepted and warrants, for example, maximum peak cladding heat or its maximum oxidation. These values cannot be overridden in any way since they would fail significant systems or components of the structure. furthermore, suitable safety margins depict variations among the determining values of allocated parameters and their actual values are prospective by the nuclear regulatory organizations. Some of them are presented directly (for example, the peak cladding temperature must not override1200 1C), and some can be expressed in relative (for example, the clad oxidation should not be higher than 17% of its thickness). There are also some further parameters not included in the regulations but extremely significant as safety or objectives in the decision-making process. Though, in any case, whether the safety parameters are restricted by regulations or only by the safety objectives when fixed quantitatively may be utilized as standard or attributes for the decision choices evaluation.

Probabilistic inputs: The Probabilistic Safety Assessment margins may be defined as the distinction among the legally binding PSA targets accepted by the regulatory organization and the values of the risk parameters calculated for the particular facility. Thus, the PSA attributes could meet the following targets: - Core damage frequency (≤ 1E -5 per year)

- Likelihood for radioactivity release (≤1E-6 per year)
- Lack of shutdown system (≤1E -6 per demand)
- Lack of engineered safety systems (≤1E- 3 per demand)
- Individual risk of calamity (≤ 1E -6 per year)
- Frequency of doses (≤ 1 mSv per year).

However, in a variance to the deterministic standards fulfilling probabilistic targets does not guarantee safety but minimizes the risk of a dangerous incident.

Economic attributes inputs: in nuclear facilities, the economic sides have less interest when compare with the safety problems. though, the decisions on nuclear facilities are often derived from economic factors. For example, the reason may be in making some changes in the design of nuclear facilities that the raising in productivity. In this situation, the necessity to analyze what are the financial opposites for reformations and evolutions when compare to the predictable return, assign the payback period, also compute if additional credit is needed.the following table1 summarized all this attributes.

Table (1): List of Different attributes for Research Reactor

IRIDM Inputs	Attributes
Deterministic Safety Assessment	- Peak clad temperature - Maximum clad oxidation - Core Coolant mass flow - Hydrogen generation
Probabilistic Safety Assessment	- Core damage frequency - Releases frequency - Shutdown system UNA - Safety systems UNA - Frequency of doses
Economy	- Benefits cost ratio - Own fund\credit ratio - Increases in productivity - Employment increases

Step 2: Utilizing Neural Network in weighting process:

In this work The neural network can be subjected to verdict the priorities risks and to calculate the weight factors that must be taken into account in the decision-making process as shown in figure 2.

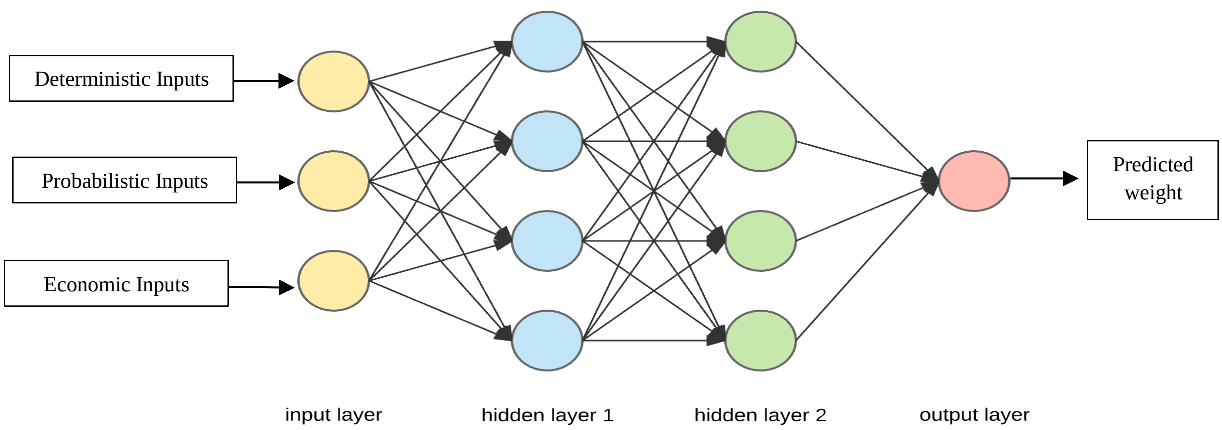

Fig. (2): Schematics of multilayer neural networks

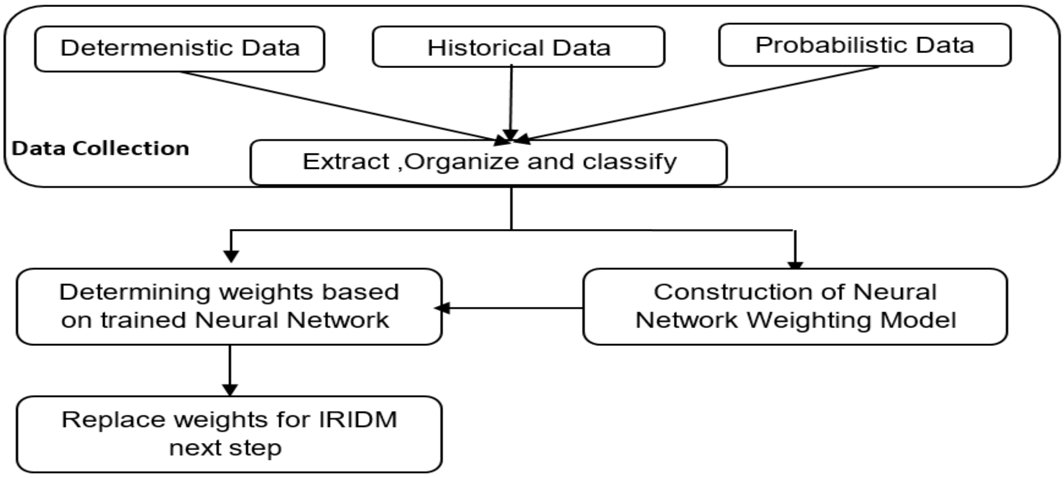

Fig. (3): proposed Neural Network in weighting process

The weighting process: feasible enforcement of the IRIDM process may be high, and tricky because of some issues related to the inputs prioritization and the decision choices evaluation. Depending on the new IAEA rules and principles the target from inputs prioritization is specifying relative numerical values from 0 – low effect, upto10 – the high effect on the decision. The weights assignment, yet, is completely individual, focuses on the engineering judgment, and dealt with the specified issue being processed [10]. An identical manner is utilized to decide the effect of the diverse IRIDM choices on certain inputs. Generally, the value is specified for each choice in the range of scores from _10 (the high negative effect) through 0(no effect) up to10 (the high positive effect). It permits to appoint the option k as the total weighted score(S_k):

$$S_k = \Sigma_i W_i \, .S_{ik} \qquad \textbf{(1)}$$

where W_i is the weighting factor of input i while S_{ik} explains the effect of choice k on input i, therefore, whole initially suggested choices can be classified through that factor and the optimum solution can be chosen. After that, approval is given for the choice with the highest grade.

3. RESULTS OF PRACTICAL APPLICATION OF AN INTEGRATED FRAMEWORK FOR DYNAMIC RISK ASSESSMENT AND DECISION MAKING

Feasible application of the IRIDM process has been executed recently in the decision-making on fuel conversion of the research reactor MARIA run by the National Centre for Nuclear Research in Poland. The conversion process objective is to substitute the high-enriched uranium fuel (HEU) consisting 36% of U-235 with the least-enriched uranium fuel (LEU) with only 17% of U-235. The decision on the fuel conversion was imposed by security causes in conformity with the Global Threat Reduction Initiative (GTRI) behests and recommendations[3]. The IRIDM method was selected to apply in the improvement of the fuel conversion process decision. The pumps exchanged before the core conversion or power limits after that were seen[8]. Three groups of specialists were selected to define how to execute this process optimally, group 1: for Deterministic Safety Assessment, group 2 : for Probabilistic Safety Assessment and group 3 : Neural Network Risk Assessment. For the three groups, the IAEA framework of IRIDM was applied, the identical choices were thought about carefully and the identical inputs were analyzed, excluding only in the third one the Risk assessmentt process applied and Taking into consideration the international regulations and principles issued by the IAEA. The framework of IRIDM includes the determination of pertinent inputs that affect the decision-making process and their prioritization regarding the severity of risks related to them [11]. The definition of risk: The risk R_i related with a particular incident scenario i can be described as a tidy pair.

$$R_i = (P_i, C_i) \qquad \textbf{(2)}$$

Where P_i describes the likelihood of an incident scenario i to happen and C_i determines the volume of the consequences corresponding to its happening. When the consequences of the incident scenario i can be specified by a continuous sequence of results between x and$x + \Delta x$, then the risk density R_i (x) of volume C_i (x) can be defined. In this case, usually great importance becomes the risk of harm overriding the acceptable limit C_i (X)[12] .

$$R_i(\geq x) = \left(P_i, \Sigma_j \int_x^{\infty} C_{ij}(x)dx\right) \qquad \textbf{(3)}$$

Where $C_{ij}(x)$ comprise a diversity of forecast consequences of type j resulting from the incident scenario i. This factor is in particular substantial in the case of a strong release of radioactivity when great than one kind of possible harm could happen and they all have to be taken into consideration through the decision-making process on preventive procedures after this accident[13].

Step 3: For the three groups, the gives weights process of the IRIDM framework inputs from organization risks and factors that were grouped and systematized in a form of a survey preceded by a joint debate in which everybody could submit an individual view.

Step 4: in the next step, the decision makers filled out the questionnaires singly by expressing the risks and factors studied by numerical values as inputs for IRIDM, by assumption 0 for weak effect and 10 for the highest effect on the decision[8]. Until now, there were many advantages to applying such an approach, particularly when compared with the traditional approach of decision-making. Until this step,the process was more structured and comprehensive. Also, the IRIDM process is more comprehensive and transparent than the traditional method of decision-making by taking into account quite a wide set of issues and considering the complex factors and variables of the work environment. However, the limitations represented in that the risk and factors prioritization and the decision choices evaluation were yet focused most on the individual verdict of the decision-makers. Meaning that there were no obviously defined standards on how the weighting factors should be designated. Also, the Participants with powerful personas may have an impact on the choices of the other participants of the discussion to select and identify risks and priorities. Therefore, to decrease the observed disadvantages of the IRIDM method, the work method of the third group was regulated in a slightly different way through apply the Neural Network for Risk Assessment. This time was requested from the specialists simply apply the steps of the risk assessment process on the inputs of the Risks, for ranked and describing their relative importance.

Step 5: Then, in the next step, the results of the IRIDM model are compared with the IAEA regulations and the targets. So the discussion was focused rather on the evaluation and assessment of the risks than on the specific numbers. Also, the main attributes were determined within the IRIDM framework inputs. The attributes prioritization was regulated in an identical method. Then, the quantitative standards for all factors were determined to depend on the safety targets, regulatory requirements, and economic expectancies. Both groups obtained the same final results, and they had three choices:

- Option 1: Core conversion before change of the pumps without additional criteria.
- Option 2: the pumps replacement before fuel conversion.
- Option 3: partial conversion before change of the pumbs with power limits criteria.

and the option number three was selected, however the method of work in the third group was more efficient and the workflow with more transparent, and evident, and had minimal sensitivity to the individual opinions of the person's decision-makers. Also, the following advantages of the risk assessment process and IAEA regulations enforcement were observed:

1- Identification of factors attributes for IRIDM inputs as a pre-step gives a profound insight into the issue to be resolved and makes the decision-making process auditable and more transparent.

2- There is a potential to partition the problem into two or more sub-problems by adding Restrictions and conditions on profound grade if needful when the step of comparing results with goals and standards, which allows applying the partition and sampling methodology through the whole decision-making process.

3- The set of Risk Management process steps applied through the proposed framework when complemented with the IRIDM process by quantitative results enables focus on and choice for the Critical problem that represents more risks that are about to occur needed for a quick decision to deal with.

4- The application of the prioritization risk and factors step makes available smooth and more precise relations for the IRIDM inputs under study.

5-Since there are already developed methods and measures tools for analysis and measurement of the factors, that makes this proposed approach to the decision-making process is more effective from a perspective of future needs and utilization.

6- Reduce the uncertainty in the decision-making process of the system of the nuclear facility.

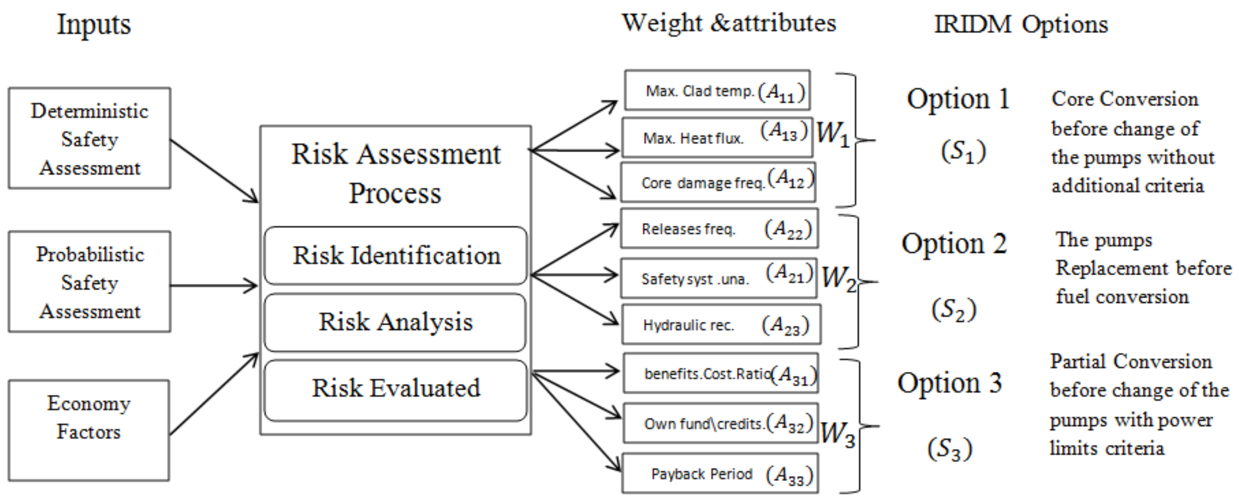

Fig. (4): the developed framework to support the decision-making process for MARIA reactor core conversion

CONCLUSION

This proposed work aimed to evolve a new framework for the IRIDM application to improve this process and make it more transparent, accurate, and auditable. The traditional IRIDM model depends on subjective judgments in selecting and determining the inputs of the risks and their priorities these have been replaced by the analysis and evaluation based on the quantitative criteria based on the risk management process as a guide in the proposed integrated framework for dynamic risk assessment and decision making. This makes the IRIDM approach well-organized and it can be applied more easily. This study complements the integration of the risk assessment process with the existing framework of IRIDM by a clear definition of studied risks and the safety limits and the targets to be accomplished in the nuclear facility .The novel framework proposed in this work allows for a significant minimization of the difficulties that the organization faces when the assessment of the IRIDM input. The other contribution and advantages of the proposed framework, as described in the case study, were specified for deciding on the fuel conversion of the research reactor MARIA. The advantages and importance of the risk assessment process and IAEA principles applied with IRIDM were confirmed by the comparison of the decision-making process executed by the two groups of specialists from which one was focused on the standard IRIDM approach, while the second group utilized the proposed integrated framework for dynamic risk assessment and decision making.

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