SUSTAINABILITY MANAGEMENT SYSTEM MODEL FOR OPERATING ORGANISATIONS OF NUCLEAR RESEARCH REACTORS

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ABSTRACT

United Nations' 2030 Agenda for Sustainable Development establishes 17 Sustainable Development Goals (SDGs). Nuclear and isotopic techniques contribute directly to achieving the SDGs related to energy, human health, food production, water management and environmental protection. This paper proposes a sustainability management system model for operating organisations of nuclear research reactors, supported by four sustainability pillars: institutional, economic, environmental and social. Each pillar of sustainability is formed by categories of indicators found in bibliographic references and validated by nuclear and sustainability academic experts, by using Delphi method. The management system model proposed has a high-level structure based on standards established by International Organisation for Standardization (ISO), considers safety requirements of International Atomic Energy Agency (IAEA) and corporate sustainability requirements found in bibliographic references. Stakeholders' requirements and expectations are inputs of the management system. The focus of the management system is nuclear safety and the organisation's commitment to sustainable development. A method for validating the sustainability management system, a sustainable development matrix to assess the maturity of sustainability management over time, and a sustainable value model, which evaluates the path taken by the organisation towards sustainable development, are tools that support the management system proposed. The management system outputs are management decisions that comply with organisation's policy, objectives and processes; products that meet stakeholders' requirements and expectations; and a Sustainability Report that contains sustainability indicators addressed by institutional, economic, environmental and social dimensions.

1. Introduction

Corporate sustainability management is an increasingly discussed topic among experts in the field of administration, but little has been discussed to date in the area of nuclear research. According to Amano [1], former Director General of the International Atomic Energy Agency (IAEA), sustainable development will be in focus at the IAEA in the coming years.

VINCZE [2] presented the evolution of management approaches applied to nuclear organisations of IAEA member countries over time, to achieve good standards of safety and performance. This evolution included some key management approaches: quality control, quality assurance, quality management and integrated management systems. The IAEA currently recommends a systemic approach to organisation leadership and integrated management for safety, but this approach is not the ultimate solution for evolution. Figure 1 illustrates the evolution of management approaches applied to nuclear organisations in IAEA member countries over time.

Operating organisations of nuclear research reactors are using management system models based on the international standards of International Organisation for Standardization (ISO) and International Atomic Energy Agency (IAEA), but these models that do not include issues of sustainability in their context.

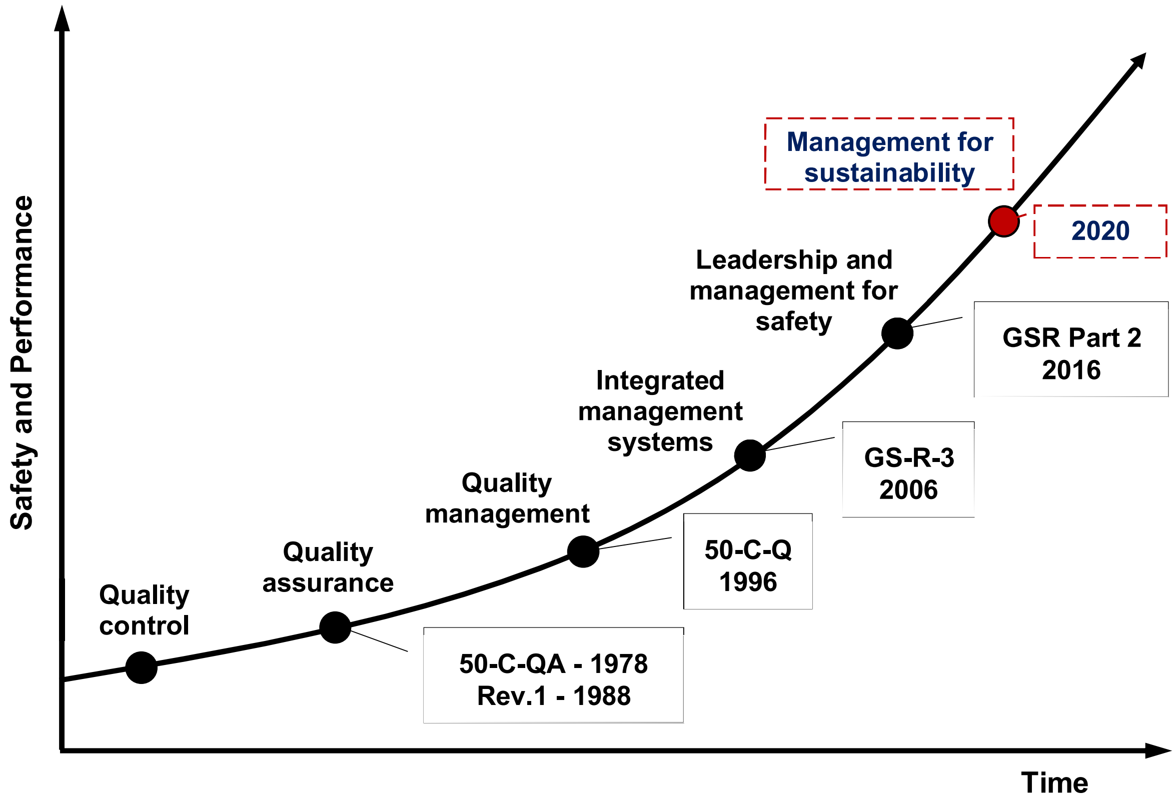

Figure 1 - Evolution of management approaches in nuclear organisations.

The purpose of this paper is to present a sustainability management system approach for operating organisations of nuclear research reactors. This proposal is in line with IAEA policy for sustainable development.

With this new proposal, in addition to maintaining high levels of safety and performance, these organisations will also be able to comply with sustainable development goals established by their competent national and international bodies.

In section 2, we present a bibliographical review on research reactors, management systems, sustainability, sustainable development and corporate sustainability. In section 3, based on bibliographical review made in section 2, we present the methodology used for the construction of the sustainability management system model for operating organisations of nuclear research reactors. In section 4, we present the sustainability management system model constructed and make an analysis on such model. In section 5, conclusions and final considerations of the study are presented. References used in the text are presented in section 6.

2. Bibliographical Review

2.1 Nuclear research reactors

Nuclear research reactors are reactors used for research, development, education and training. Their main function is to produce neutrons for use in industry, medicine, agriculture and forensic science.

A nuclear research reactor is a large enterprise that demands a lot of attention to nuclear safety and security, international safeguards and the control of nuclear materials.

A well-structured strategic planning, a consistent management and an adequate funding are essential to ensure the safe and efficient operation of nuclear research reactors.

IAEA [3] provides a database of nuclear research reactors. According to this database, there are currently in the world 220 nuclear research reactors in operation, 9 in construction, 14 planned, 15 with temporary shutdown, 13 with extended shutdown, 60 with permanent shutdown, 67 decommissioning and 443 decommissioned.

The lifespan of a nuclear research reactor may vary from 40 to 60 years, but there is a possibility to extend this lifespan by modernization of these reactors. Increasing research reactor lifespan by modernization characterizes an increase in its operation sustainability.

2.2 Management systems

ISO [4] and IAEA [5] defined management system as a set of interrelated or interacting elements (system) for establishing policies and objectives and enabling the objectives to be achieved in an efficient and effective manner. The component parts of the management system include the organisational structure, resources and organisational processes. The management system integrates all elements of an organisation into one coherent system to enable achieving all organisation's objectives. Personnel, equipment and organisational culture as well as documented policies and processes form parts of the management system. The organisation's processes have to address the totality of the requirements on the organisation as established in, for example, IAEA safety standards and other international codes and standards.

2.2.1 ISO Management systems

According to ISO [6], ISO management system standards must follow a model, characterized by a high-level structure, with identical main text, common terms and main definitions and which contains six common requirements: context of the organisation, leadership, planning, support, operation, performance evaluation and improvement.

The six common requirements shall be observed in conjunction with the PDCA (Plan-Do-Check-Act) approach, which all management systems follow:

- Plan (P): context of the organisation, leadership, planning, support;
- Do (D): operation;
- Check (C): performance evaluation; and
- Act (A): improvement.

In Figure 2, the common requirements used in the ISO management system standards and their interaction with the PDCA cycle are presented.

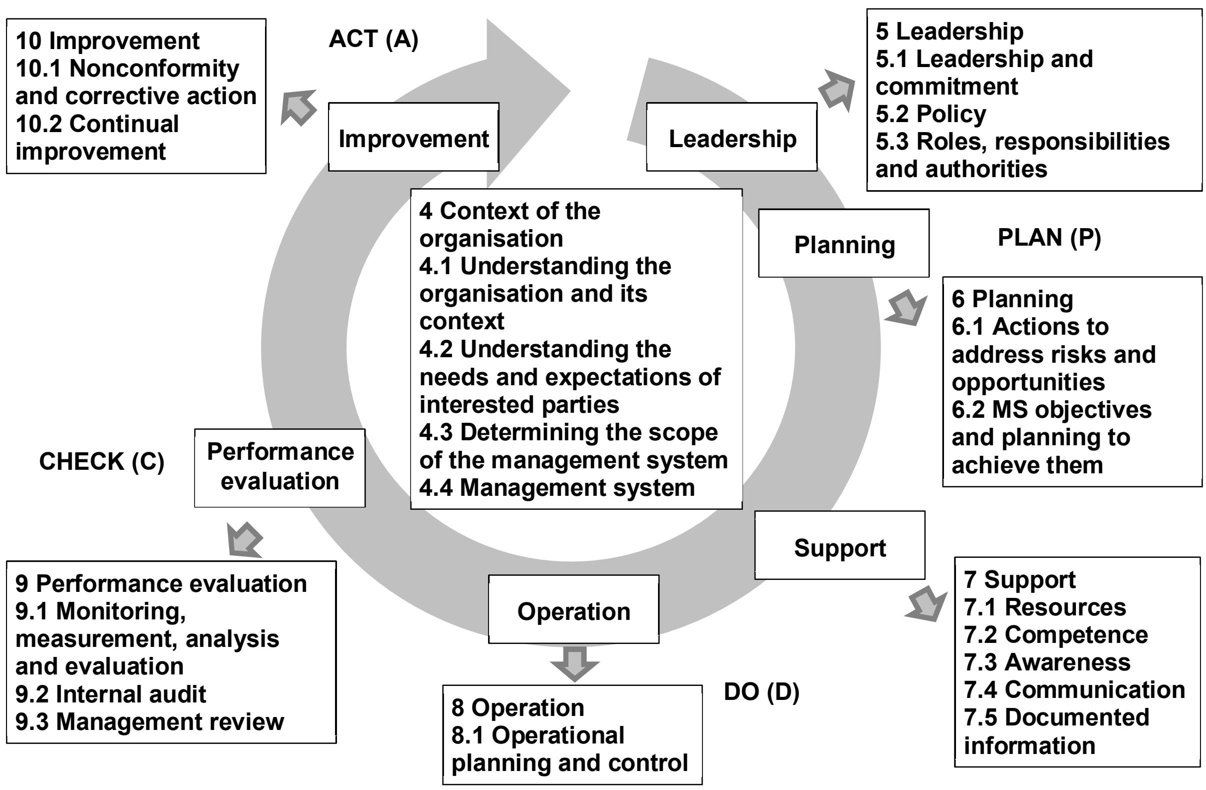

Figure 2 - Common requirements for a high-level management system.

2.2.2 IAEA Management systems

IAEA SSR-3 [7] describes that an operating organisation of a nuclear research reactor shall establish, implement, evaluate and continuously improve an integrated management system, which must be unique, with all components integrated to enable the organisation's objectives to be achieved. This management system shall integrate all management elements, including occupational safety, health, environment, security, quality, human and organisational factors, social and economic elements.

IAEA GS-R-3 [8] describes that the management system of a nuclear organisation shall operate in four functional categories:

a) Senior management responsibility: providing the means and support necessary to achieve the organisation's objectives in matters of safety.
b) Resource management: ensure the determination and availability of the indispensable resources for the execution of the organisational strategy and the achievement of the organisation's objectives. The term "resources" encompasses people, infrastructure, the work environment, information, knowledge and suppliers, as well as material and financial resources.
c) Process Implementation: ensure that the processes developed to achieve the goals of the organisation and its products are carried out in accordance with established codes, standards, specifications, procedures and administrative controls. The implementation of the process shall consider changes, modifications or subsequent improvements in safety, construction, commissioning, operation and decommissioning of the reactor.
d) Measurement, evaluation and improvement of the management system: regularly measure and evaluate the effectiveness of the management system through independent evaluations and self-assessments, and take the necessary measures to achieve continuous improvement.

In Figure 3, SMETNIK and MURLIS [9] presented a typical management system model of a nuclear organisation, and the relationship between the four functional categories described above.

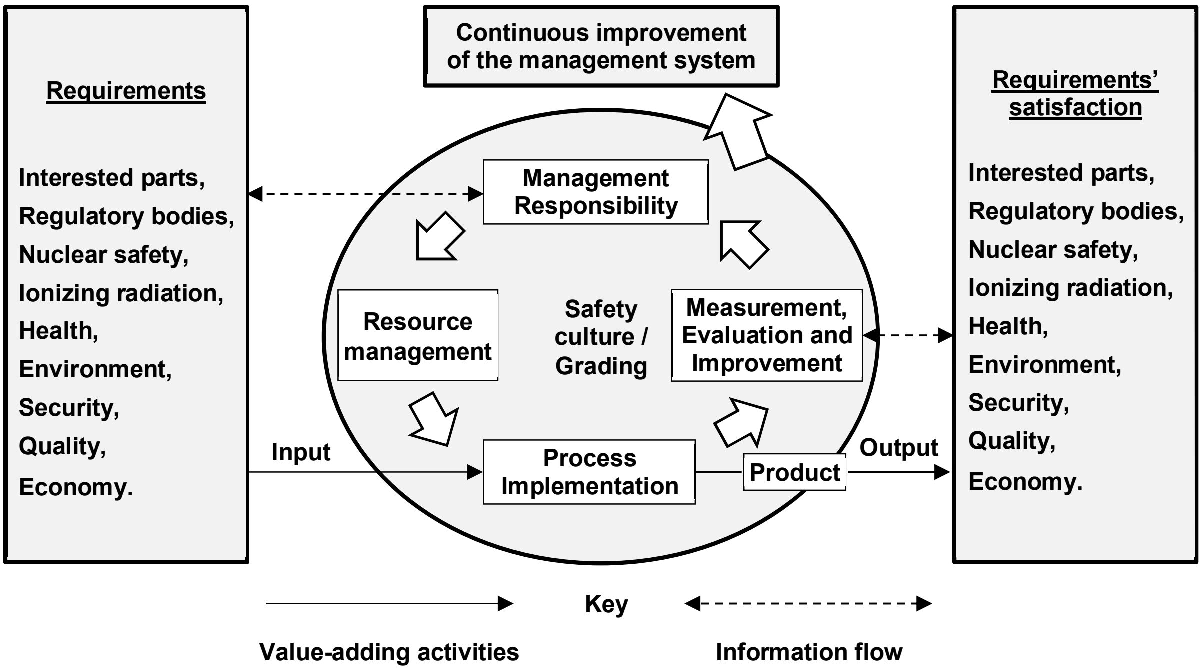

Figure 3 - Typical management system model of a nuclear organisation.

IAEA GS-R-3 [8] has been replaced by the IAEA GSR Part 2 [10], which, as a requirements standard, does not provide any guidance on how the management system for a nuclear organisation shall be configured.

In Figure 4, a structure for a management system for a nuclear organisation is proposed by IAEA [11], based on the requirements of IAEA GSR Part 2 [10].

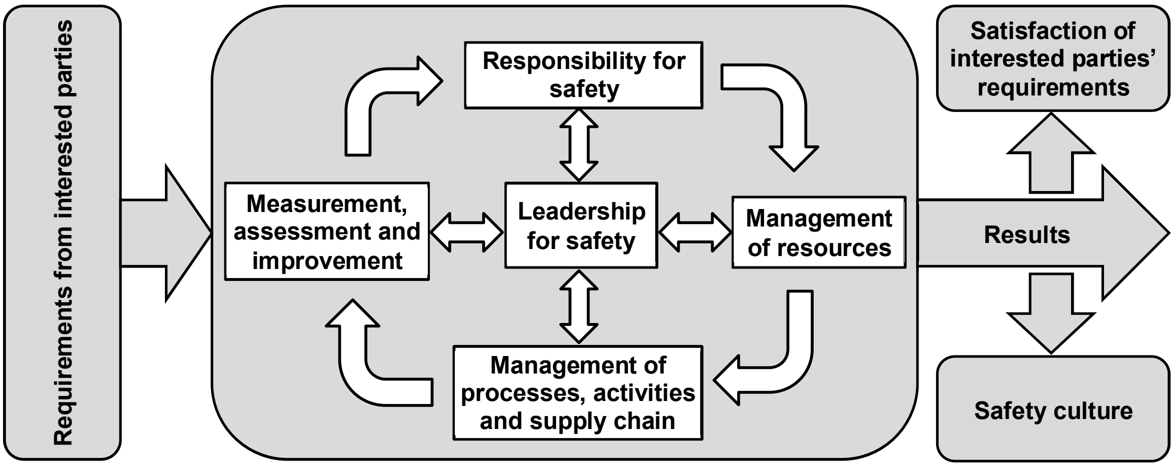

Figure 4 - Interaction among processes covered in IAEA GSR Part 2 [10].

The processes shown in Figure 4 are described below:

a) Responsibility for safety: senior management is responsible for safety at all stages of a nuclear enterprise, and in particular, for equipment, radioactive material, ionizing radiation sources, radiation exposure risks, provision of resources and preparation to respond in emergencies.
b) Leadership for safety: senior management shall demonstrate leadership in dealing with people with respect to the priority that should be given to safety over other requirements, fostering a strong safety culture.
c) Management of resources: senior management shall provide resources to maintain the necessary competencies to carry out activities safely, select internal and external employees, provide training to maintain employee competence, and treat knowledge as a resource.
d) Management of processes, activities and supply chain: includes meeting requirements, documentation, records, interface between processes, modifications, inspection, testing, control of processes that impact safety, contracting, acquisition, qualification of suppliers, so that safety is not compromised.
e) Safety culture: individual and team awareness of the risks and dangers of ionizing radiation, collaborative attitude, reporting technical and human problems, reporting defects in structures, systems and components, attitude towards questioning and learning, safety-based decisions, integration with security culture.
f) Measurement, evaluation and improvement: monitoring, evaluation and measurement of management system effectiveness, always seeking its improvement, treatment of non-conformities related to safety, corrective actions, critical analysis by senior management, independent evaluation, communication of evaluations to all levels of the organisation.

For the operation stage, the management system of an operating organisation of a nuclear research reactor shall specifically guarantee:

- safe operation of the nuclear research reactor, within the limits and conditions specified in the operating license, in order to protect the public, workers and the environment from the risks of undue radiation;
- compliance with regulatory requirements;
- adequate and safe modification, renovation and modernization;
- forecasting changes, including organisational changes and the cumulative effects of minor changes, which could have significant security consequences;
- independent verification before important safety decisions are taken;
- safe and effective use of nuclear research reactor facilities, including quality control of products and services delivered; and

- better operational performance of the nuclear research reactor, as well as maintenance programs and procedures.

For the implementation of a management system by a nuclear organisation, the guidelines established by IAEA SRS 75 [12] shall be followed.

The key elements for the successful implementation of the management system are described below:

- the person in the highest management position in the organization is responsible for ensuring that the management system is implemented;
- there shall be a collaborative effort between management, those who do the work and those who verify the work;
- the planning and provision of adequate resources;
- the entire team is trained to achieve proficiency and ensure that people understand the procedures applicable to the performance of their work;
- understanding that the interactions between the organization's processes can be complex, resulting in a network of interdependent processes, whose inputs and outputs are often related to internal and external customers;
- understanding that individual work processes rarely occur in isolation: outputs from one process are usually inputs from the subsequent process;
- alignment of the complexity of the activity to the complexity of the documentation: a simple activity can be addressed in a single procedure, while a process is implemented by applying one or more procedures and / or work instructions;
- grouping of various processes, instead of implementing each process and related documents sequentially, in order to reduce the time and effort required for implementation;
- conducting dedicated internal audits to monitor and facilitate implementation, after the management system has been started;
- assessment of the effectiveness of the management system at all stages of implementation;
- continuous improvement of work performance, using information acquired from evaluations.

In Figure 5, an overview of the implementation of the management system proposed by the IAEA SRS 75 [12] is presented.

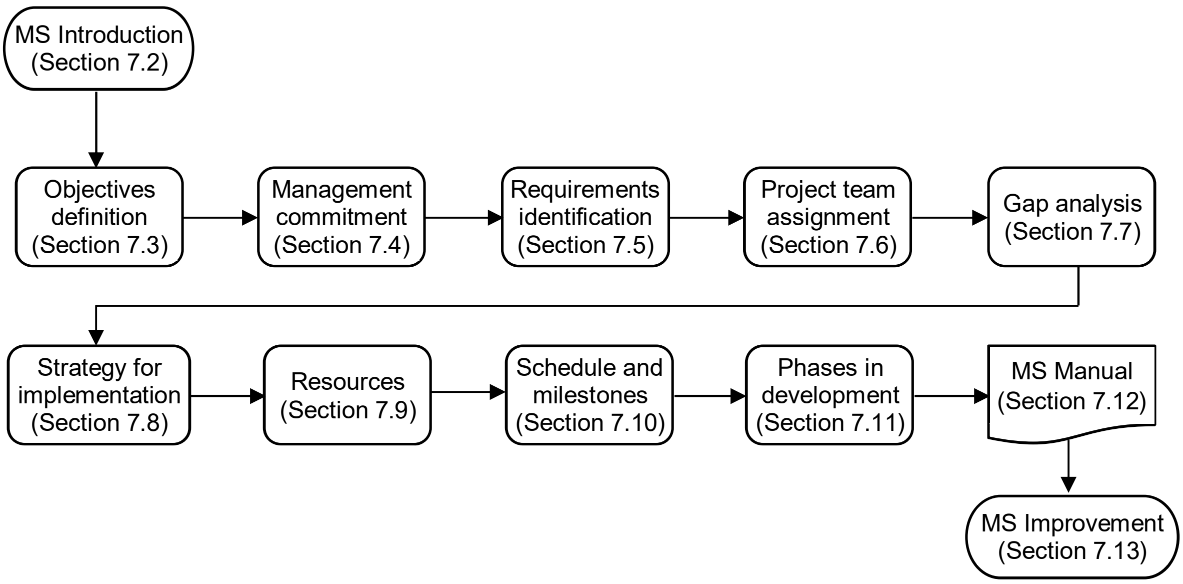

Figure 5 - Overview of the implementation of the management system proposed by the IAEA SRS 75 [12].

2.3 Sustainability, sustainable development and corporate sustainability

2.3.1 Sustainability and sustainable development

According to the FUNDAÇÃO NACIONAL DA QUALIDADE [13], the term “sustainable” originated from the Latin word “*sustentare*” and means to sustain, defend, favour, support, conserve, care. The concept of sustainability is related to the expression “sustainable development”, which was widely disseminated in 1987, from the report published by United Nations World Commission on Environment and Development, called Our Common Future. In this report, “sustainable development” was defined as development that meets the needs of the present, without compromising the ability of future generations to meet their own needs. This definition continues to be used to this day.

In September 2015, United Nations (UN) published Resolution A/RES/70/1 [14], known as the United Nations 2030 Agenda, which established 17 Sustainable Development Goals, as shown in Figure 6.

Figure 6 - 17 Sustainable Development Goals (SDGs) in United Nations 2030 Agenda.

The 17 SDGs reflect fundamental needs in order to prosper and conserve our planet, but reaching them is not simple. Among other reasons, the complexity in achieving these objectives is largely due to the current view of organisations in relation to sustainable development. It is common to come across situations in which an organisation cannot be aligned with this concept simply because it does not understand its own socio-environmental impact, its sustainability context and the risks involved.

IAEA [15] supports many countries to use nuclear and ionizing radiation techniques in areas such as energy, human health, food production, water management and environmental protection. Thus, nuclear technology directly contributes to the achievement of nine of the seventeen SDGs, as described below:

a) SDG 2 - Zero hunger: use of nuclear and isotopic techniques to protect plants from insect pests and create new varieties of plants that show, for example, better crop yields, resistance to diseases or drought tolerance.

b) SDG 3 - Good health & wellness: fighting cancer using nuclear medicine, radiation oncology and radiology facilities, support for education and training of skilled health professionals.
c) SDG 6 - Clean water and sanitation: study of the quality and quantity of water resources, detection and analysis of pollutants, using isotopic techniques.
d) SDG 7 - Affordable and clean energy: promotion of efficient and safe use of nuclear energy, support for nuclear programs worldwide, catalysing innovation and strengthening capacity in the planning, analysis and management of nuclear information and knowledge.
e) SDG 9 - Industry, innovation and infrastructure: use of radiation, such as electron beams or gamma rays in the sterilization of products, food, or cultural artefacts, in the cleaning of contaminants from industrial wastewater and air and in the modification of materials for increase its useful life; use of radioactive tracers to diagnose and improve industrial processes; performing non-destructive tests using X-rays, gamma rays or neutrons, to identify cracks and flaws in materials and structures; use of waste heat from nuclear power plants to desalinate seawater, extract and produce hydrogen.
f) SDG 13 - Climate action: use of nuclear and isotopic techniques to collect data and monitor pollutants and greenhouse gases; use of nuclear energy in the energy matrix to reduce emissions of greenhouse gases, such as carbon dioxide, nitrous oxide and methane; use of nuclear science and technology in the cultivation of food with less environmental impact and in the production of food in adverse climatic conditions.
g) SDG 14 - Life below water: use of isotopic techniques to monitor ocean acidification, track and understand how contaminants, such as microplastics, radionuclides and heavy metals, affect marine organisms and ecosystems, as well as assess seafood quality and the transfer of contaminants throughout the food chain.
h) SDG 15 - Life on land: use of nuclear techniques to assess soil quality, study how crops absorb nutrients and how the soil moves; track and prevent contaminants from harming the environment; protect the environment from radiation contamination as a result of a nuclear or radiological incident or accident.
i) SDG 17 - Partnerships for the goals: forming partnerships with the United Nations Food and Agriculture Organisation (FAO), the World Health Organisation (WHO) and the United Nations Educational, Scientific and Cultural Organisation Culture (UNESCO) to support development around the world; and the carrying out of coordinated research and technical cooperation projects in the form of training, scholarships, scientific visits, supply of equipment and specialized consultancy.

Operating organisations of nuclear research reactors are characterized by supporting technological development, strengthening scientific research, improving technological capacities in industrial sectors, encouraging innovation, substantially increasing the number of research and development workers. These organisations have a strong positive impact in achieving SDG 9, described above.

2.3.2 Corporate sustainability

From 1997 onwards, the concept of sustainable development was also perceived in the business world, with the publication of John Elkington's book, entitled “Cannibals with fork and knife: the triple baseline in 21st century business”. In this book, Elkington describes corporate sustainability as a new business model that considers the balance of the organisation's economic, environmental and social factors. This business model was known as the Triple Bottom Line or Sustainability Tripod and consisted of three pillars, also known as the three P’s - people, planet and profit, characterized below:

- "People" is the social pillar of the tripod, refers to the treatment of the human capital of a company or society, considers fair wages, the well-being of employees, the impact of the business on the surrounding communities and the suitability labour legislation;
- "Planet" is the environmental pillar of the tripod, it refers to the natural capital of a company or society, it considers the reduction or compensation of the negative environmental impacts generated by the business and the adaptation to the environmental legislation;
- "Profit" is the economic pillar of the tripod, it refers to financial capital, it is the positive economic result of a company, and it takes into account the other two pillars.

The three pillars (3Ps) of the Sustainability Tripod mentioned above are also referred to in literature as dimensions of sustainability: the economic dimension refers to "profit", the environmental dimension refers to "planet" and the social dimension refers to "people". They shall be managed in an integrated manner in the small, medium and long term, to ensure the company's sustainability.

In this paper, we introduced the institutional dimension to Elkington's sustainability model, which considers aspects of sustainability and others established in the strategic management of operating organisations of nuclear research reactors.

In Figure 7, Elkington's Sustainability Tripod is shown, with the inclusion of the institutional dimension in the centre of the Tripod, which interacts directly with the three other dimensions. This structure will be used for the configuration of the sustainability management system model for operating organisations of nuclear research reactors.

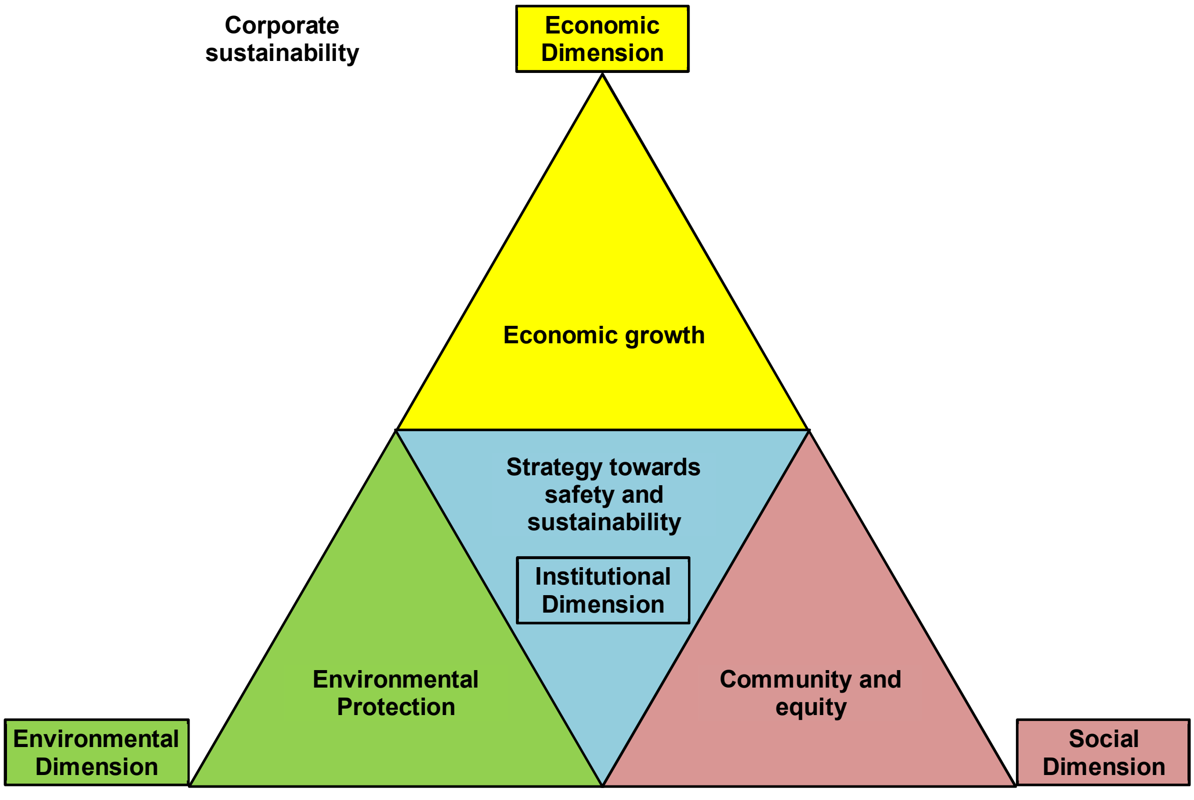

Figure 7 - Corporate sustainability approach in four dimensions: institutional, economic, environmental and social.

BS 8900-1:2013 [16] provides guidance on managing sustainable development and a framework that assists organisations to enhance performance and effectiveness. It offers a coherent approach to managing social, economic and environmental aspects of an organisation's activities.

Four fundamental principles for the sustainable development of an organisation are established in BS 8900-1:2013 [16]:

a) Inclusivity: a clearly expressed intention or policy of including key stakeholders in the development of organisational strategy, corporate planning and direction;

b) Integrity: adherence to a set of commonly held ethical norms and law-abiding behaviour;

c) Stewardship: organisation’s responsibility for the management of all facets of its activities throughout all the stages of its life span;

d) Transparency: openness about decisions and activities that affect society, the economy and the environment, and a willingness to communicate these in a clear, accurate, timely, honest and complete manner.

Each organisation shall, from time to time, determine its position along a sustainable development path. A useful tool for this purpose is the maturity matrix for sustainable development shown in Figure 8.

Principles	**Practices**	**Stages of an organisation’s approach to sustainable development** **Maturity** →			
Inclusivity					**Additional plans and objectives to be determined by each organisation may be added to the matrix.**
Integrity					
Stewardship					
Transparency					
Additional principle(s) applicable to each organisation may be added to the matrix					

Figure 8 - Maturity matrix model for sustainable development.

Sustainability management systems models shall be validated by use. Munck et al. [17] use the Interconnected Cycle of Legitimation and Qualitative Validation, shown in Figure 9, to qualitatively analyse the validity of sustainability management models.

Throughout this cycle, the analysis of an organisational sustainability management model shall start at the stage of constitutive and operational definition and proceed to the stage of predictive validity, until the validity is fully granted.

Construct validity encompasses the stages of content validity, face validity, reliability and predictive validity.

The content validity stage indicates that the descriptors of the concepts selected to compose the model represent a representative sample of the universe of interest.

The face validity stage indicates whether the concepts present in the model and required by the organisation are appropriate, when analysed by employees who develop them.

The reliability stage indicates the level of precision with which the model's component concepts are measured.

The predictive validity stage indicates whether the model adopted and its respective concepts contribute to improvements in individual and / or organisational performance.

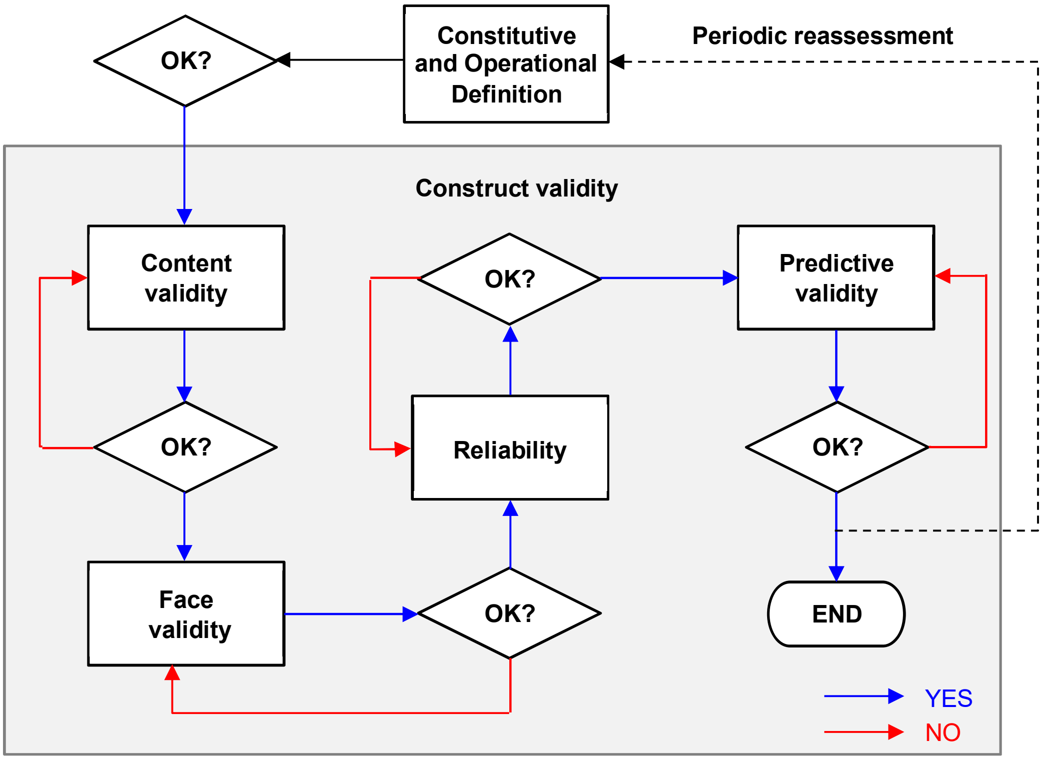

Figure 9 - Interconnected Cycle of Legitimation and Qualitative Validation.

Hart and Milstein [18] present in Figure 10 a complex and multifaceted model for creating sustainable value that takes into account the global challenges of sustainable development. According to them, global sustainability inserted in companies should contribute with economic, social and environmental benefits. For them, sustainability can become a business opportunity, adopting the multidimensional model of creating sustainable value.

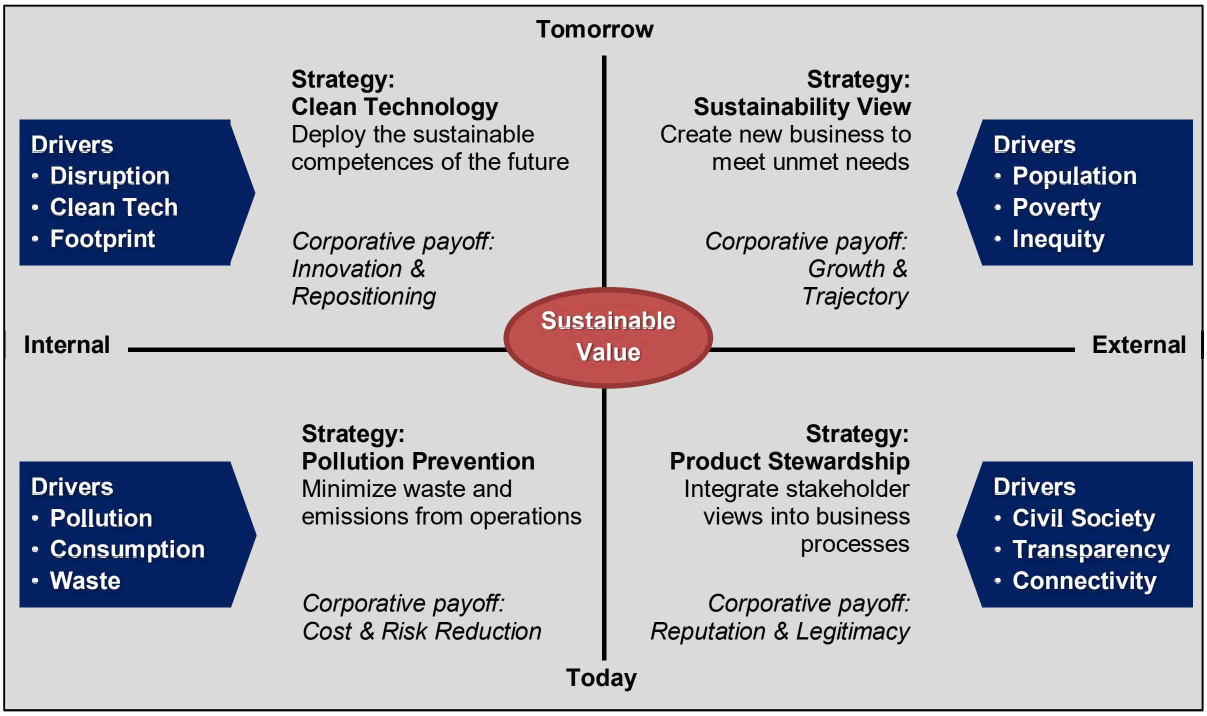

Figure 10 - Sustainable value model.

HART and MILSTEIN model [18] represented in Figure 10 consists of a vertical axis, which reflects the company's need to maintain current businesses and to invest and create technologies for the future; and a horizontal axis, which reflects the need for growth of the company and to spread new perspectives and external knowledge within the company.

Thus, sustainable value is generated in quadrants, cost and risk reduction in the lower left; reputation and legitimacy in the lower right; innovation and repositioning the upper left and growth and trajectory in the upper right.

In Figure 10, the global drivers of sustainability can also be observed in each quadrant of the model suggested by HART and MILSTEIN [18]. The first driver is industrialization, which, despite the benefits generated, also brought about the exacerbated consumption of raw materials, pollution and a large generation of waste. The second driver relates to civil society stakeholders who challenge companies to operate transparently, given that they are well informed. The third driver relates to emerging technologies that offer powerful solutions to pollution. And finally, the fourth driver relates to population growth, poverty and inequity that accelerates social decay and the lack of resources for those who need it most. HART and MILSTEIN [18] argue that a company will only create sustainable value when it considers these four drivers.

For companies and organisations of all sizes be aligned with sustainable development goals (SDGs), it is necessary that they adopt a methodology which allows them to measure variables, empower leaders to take key decisions, encourage employees to engage in the search for better processes and, finally, demonstrate not only the viability of these processes, but guide the organisation to follow them fully and rationally.

The voluntary practice of issuing sustainability reports by large organisations shows the commitment of these organisations to sustainable development and the degree of implementation of sustainability requirements in their management system. By issuing these reports, organisations demonstrate their proactivity in preventing the occurrence of economic, environmental and social impacts in the space where they operate.

The sustainability reports bring together sets of indicators linked to the three dimensions of sustainability, through which companies can be accountable to their stakeholders, can self-assess and, mainly, incorporate sustainability principles in their practices.

A good sustainability report allows the development of a management strategy focused on the future, based on consistent information on the positive and negative impacts of sustainability, both caused by the company and by external factors, such as climate change or human rights issues. It also improves the dialogue between stakeholders, identifying risks and opportunities related to sustainability, and better business and innovation opportunities.

3. Methodology

The methodology used for the construction of the sustainability management system model for operating organisations of nuclear research reactors consisted of two stages, as shown in Figure 11.

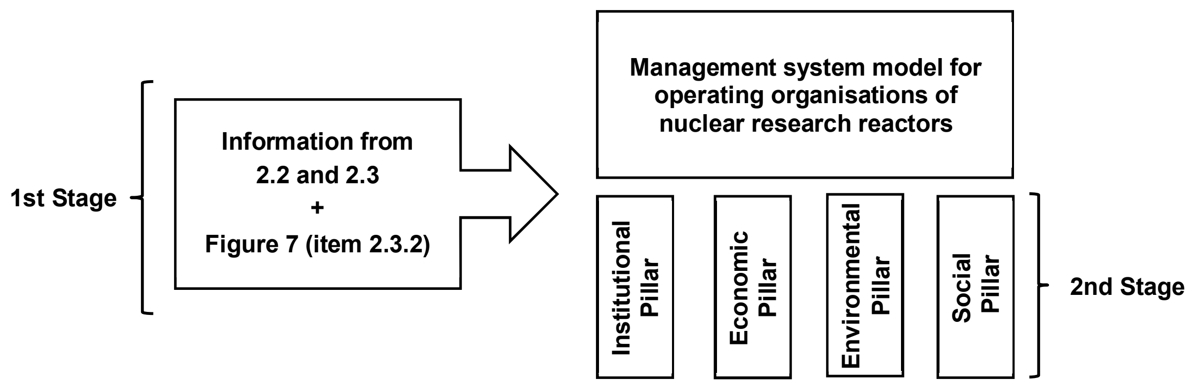

Figure 11 - Simplified schematic diagram used for the construction of the sustainability management system model for operating organisations of nuclear research reactors.

The first stage consisted of a bibliographic review on management systems for nuclear research reactors and corporate sustainability. The management system requirements addressed in 2.2, the corporate sustainability requirements and tools presented in 2.3, and Elkington's sustainability management model presented in Figure 7, including the institutional dimension, were considered for the construction of the sustainability management system model for operating organisations of nuclear research reactors.

The second stage consisted of a field survey performed with nuclear and sustainability academic specialists, which followed Delphi Method.

ALVES [19] proposed the Delphi method for the construction of sustainability indicators for nuclear research institutes, which consisted of:

- Bibliographic survey: literature review, critical analysis of literature, conceptualization about sustainability and sustainability indicators, nuclear technology indicators and nuclear technology sustainability indicators.
- Proposition of sustainability indicators: construction of an array of sustainability indicators for operating organisations of nuclear research reactors;
- Validation of the sustainability indicators: validating the proposed sustainability indicators through the Delphi method (Figure 12).

Based on ALVES [19] methodology, we performed the construction of sustainability indicators for nuclear research reactors operating organisations in this paper, as shown in Figure 12.

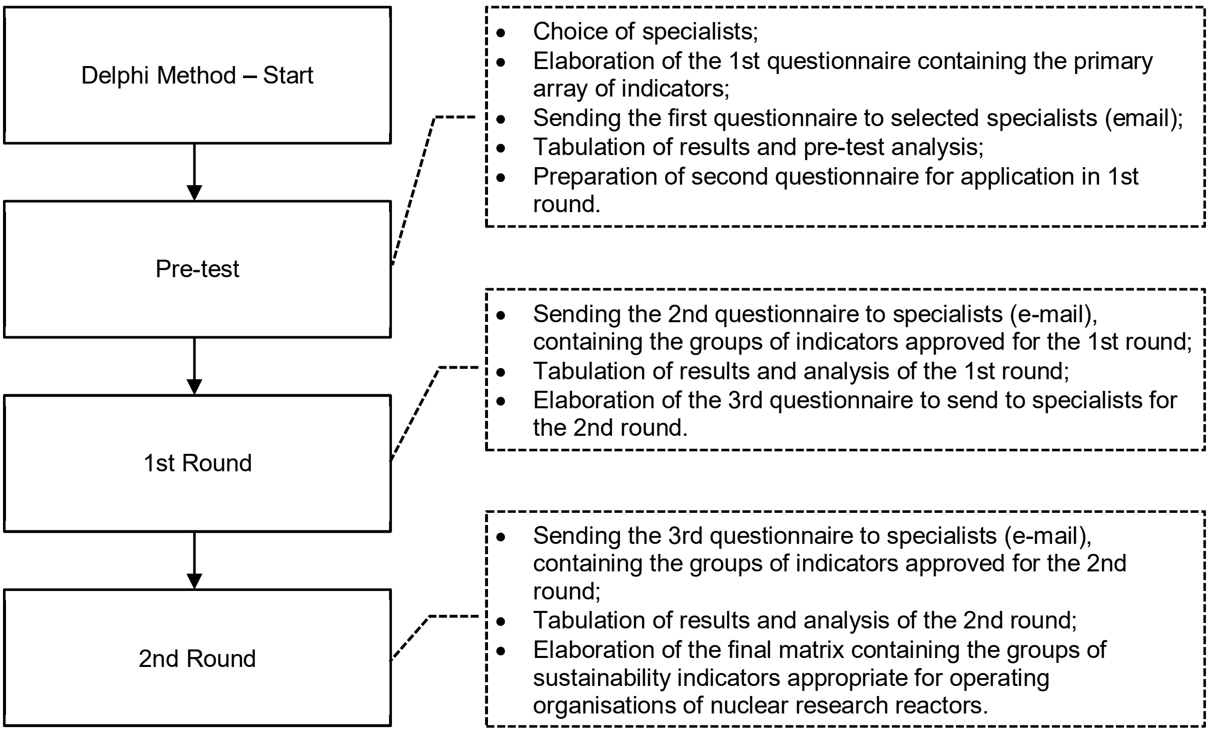

Figure 12 - Delphi method flowchart used in this paper.

4. Presentation and Analysis of Results

4.1 Presentation of results

For the application of Delphi method, 174 specialists were selected and contacted for the pre-test. Of these 174 specialists, 60 accepted to participate in the research, but effectively 38 specialists responded to the preliminary spreadsheet sent. In the First Round there were 34 respondents and in the Second Round, 30 respondents.

The pre-test stage was carried out from 11-Dec-2018 to 14-Feb-2019. At this stage, the preliminary spreadsheet with groups of sustainability indicators pre-defined by the author, obtained from the bibliographic research, was sent for analysis by pre-selected specialists.
In the pre-test stage, the preliminary spreadsheet of groups of indicators contained 61 groups of indicators for the institutional dimension, 49 for the economic dimension, 68 for the environmental dimension and 61 for the social dimension, totalizing 239 groups of indicators.
The compilation of responses and comments received from analysts in the pre-test resulted in the disapproval of eight groups of the institutional dimension, 12 of the economic dimension, 16 of the environmental dimension and 12 of the social dimension, totalizing 48 groups of indicators disapproved in the pre-test stage.
At the end of the pre-test stage, after compiling the comments received from analysts, the compiled spreadsheet of indicator groups accounted for 52 indicator groups for the institutional dimension, 33 for the economic dimension, 48 for the environmental dimension and 55 for the social dimension, totalizing 188 groups of indicators, with a reduction of 51 groups of indicators in relation to the preliminary spreadsheet.
The First Round of Delphi method was held from 24/Feb/2019 to 15/Apr/2019. In this stage, the spreadsheet received from the pre-test with the 188 groups of indicators was sent for analysis by the same specialists who participated in the pre-test stage.
Of the 38 participants in the First Round, four did not return the preliminary spreadsheet. In the same way as performed in the pre-test stage, the 34 experts analysed and recorded their responses, observations and comments in this new spreadsheet, sending the responses to the author, who compiled the responses.
The compilation of responses and comments received from analysts in the First Round resulted in two groups of institutional dimension disapproved, six in the economic dimension, five in the environmental dimension and seven in the social dimension, for a total of 20 groups indicators disapproved.
At the end of the first round of the Delphi method, the compiled groups of indicators spreadsheet accounted for 50 groups of indicators for the institutional dimension, 27 for the economic, 42 for the environmental and 48 for the social dimension, totalizing 167 groups of indicators, with a reduction of 21 groups of indicators in relation to the First-Round spreadsheet.
Of the 34 participants in the First Round, five did not return the spreadsheet and a pre-test specialist, who justified his absence in the First Round, sent their analysis of the Second Round. In the same way as performed in the pre-test, the 30 experts analysed and recorded their responses, observations and comments in this new spreadsheet, sending the responses to the author, who compiled the responses.
The compilation of responses and comments received from analysts in the Second Round resulted in three groups of indicators of the economic dimension and one of the economic dimension disapproved, in a total of four groups of indicators disapproved.
At the end of the Second Round of the Delphi method, the compiled groups of indicators spreadsheet accounted for 50 groups of indicators for the institutional dimension, 25 for the economic, 38 for the environmental and 46 for the social dimension, totalizing 159 groups of indicators, with a reduction of eight groups of indicators in relation to the First-Round spreadsheet. The process of questionnaire rounds reached the desired levels of stability and consensus in the answers, and the Delphi Method ended in the Second Round.
KIBRIT [20] presents the final spreadsheet of groups of indicators identified in the Delphi method. The categories of the groups of indicators identified in the Delphi method formed the pillars of sustainability of the sustainability management system model for operating organisations of nuclear research reactors.

In Figure 13, the management system model for operating organisations of nuclear research reactors proposed in this work is presented, constructed according to the simplified schematic diagram presented in Figure 11 and with an indication of the stages of the PDCA cycle and sustainability pillars.

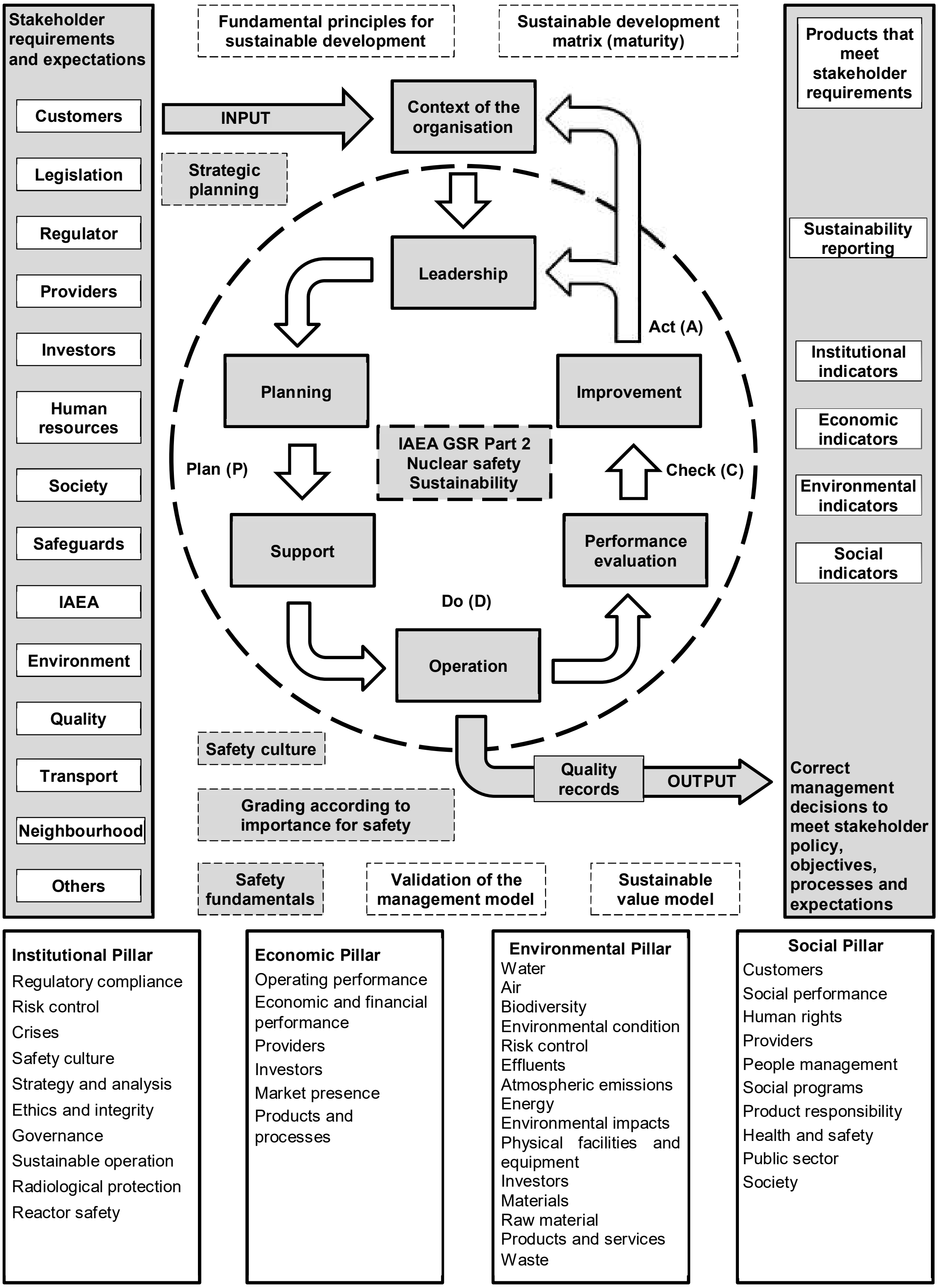

Figure 13 - Sustainability management system model for operating organisations of nuclear research reactors, with indication of the stages of the PDCA cycle and sustainability pillars.

4.2 Analysis of results

The management system model presented in Figure 13 is a theoretical model that can be applied to any type of organisation operating a nuclear research reactor. This model has a high-level structure and is used in all management system standards developed by the International Organisation for Standardization (ISO). The application of this model favours the improved use of resources, better risk management and greater stakeholder satisfaction in meeting their requirements and expectations. This structure allows the integration of safety requirements of a nuclear research reactor and sustainability requirements to the management system.

The structure of the proposed management system facilitates integration with other management systems already implemented in some organisations, such as the ISO 9001 quality system and the ISO 14001 environmental management system. The adoption of this model will avoid conflicts, duplicate requirements, confusion and disagreement, generated by models with different structures and the evaluation of the management system is facilitated.

In this way, the requirements established by the IAEA management standards can be integrated into the management system, ensuring the nuclear safety of the operation of a nuclear research reactor and the establishment of a strong safety culture.

The tools for corporate sustainability management allow assessing the organisation's maturity in relation to sustainable practices and whether the organisation's path towards sustainable development is satisfactory.

The pillars of sustainability related to the institutional, economic, environmental and social dimensions provide the necessary support to the management system to ensure that the organisation acts in a sustainable manner, without compromising nuclear safety in its operation.

The sustainability management model presented in Figure 13 shall be validated by use. For this, it is recommended to use the Interconnected Cycle of Legitimation and Qualitative Validation, presented in Figure 9. The model will be validated when it satisfactorily passes through all stages of this cycle.

The groups of sustainability indicators obtained from using the Delphi method made it possible to identify the related categories in each dimension of sustainability, constituting the respective sustainability pillars that support the management system model presented in Figure 13. The organisation will be sustainable, when the categories of indicators in the sustainability pillars are fully met.

By including sustainability in the strategic management, operating organisations of nuclear research reactors will be able to use the groups of indicators identified in this research as a reference in the measurement, evaluation and improvement of their management systems. Sustainability reports can also be prepared based on these groups of indicators, demonstrating the commitment of these organisations to sustainable development.

5. Conclusions and Final Considerations

Sustainable development will be on the agenda at the IAEA in the coming years and, therefore, this research is in line with IAEA policy, through the development of a systematic study in this direction.

This research addressed sustainability in the strategic management of operating organisations of nuclear research reactors and generated unprecedented academic contributions on the subject, which can be applied by these organisations.

The research performed consisted of two research stages: development of a sustainability management system model for organisations operating nuclear research reactors and the identification of groups of sustainability indicators for operating organisations of nuclear research reactors.

For the development of the sustainability management system model for operating organisations of nuclear research reactors, extensive bibliographic and documentary research was carried out on sustainability, sustainable development, corporate sustainability, and management systems. The model constructed is an unprecedented academic contribution, since no similar academic approach for this purpose has been undertaken.

The proposed sustainability management system model has a high-level structure, facilitates integration with other management systems and is suitable for integrating nuclear safety and sustainability requirements.

In addition, the proposed management system model corroborates the sustainability management model proposed by Elkington, known as the “Triple Bottom Line” or “Sustainability Tripod”, and introduces a fourth dimension of sustainability, the “institutional dimension”, which portrays the organisation's strategy to move towards sustainable development and highlights the importance of its finalistic processes.

A good system of performance indicators in an organisation allows an analysis of the effectiveness of management and its results. The systematic, structured and balanced measurement of results through performance indicators allows organisations to make the necessary interventions based on relevant and reliable information, as variations between planned and realized occur.

For this purpose, groups of sustainability indicators for operating organisations of nuclear research reactors were identified in a bibliographic and documentary research, and validated by academic experts, using Delphi method.

Delphi method application was satisfactory, since in just two rounds, after a pre-test round, consensus was reached among the experts. Thus, the proposal for sustainability indicators had a scientific basis supported by the opinion of experts in the nuclear and sustainability area, making the study more accurate and reliable.

In addition to the identification and validation of the groups of sustainability indicators, this research stage allowed the identification of the categories of the sustainability pillars that support the sustainability management model: institutional, economic, environmental and social.

The pillar of the institutional dimension was made up of the following categories of indicators: regulatory compliance, risk control, crises, safety culture, strategy and analysis, ethics and integrity, governance, sustainable operation, radiological protection, reactor safety.

The pillar of the economic dimension was made up of the following categories of indicators: operating performance, economic and financial performance, suppliers, investors, market presence, products and processes.

The pillar of the environmental dimension was made up of the following categories of indicators: water, air, biodiversity, environmental condition, risk control, effluents, atmospheric emissions, energy, environmental impacts, physical installations and equipment, investors, materials, raw materials, products and services, waste.

The pillar of the social dimension was made up of the following categories of indicators: customers, social performance, human rights, suppliers, people management, social programs, product responsibility, health and safety, public sector, society.

Today, the demand for organisations that demonstrate their commitment to sustainability and sustainable development is a market requirement and sustainability reporting is the certificate that organisations issue to prove this commitment.

A nuclear organisation shall demonstrate, above all, compliance with IAEA nuclear legislation and safety standards. It shall identify the structures, systems and components that are important to nuclear safety, assign a graded approach to the requirements of the management system, foster a strong safety culture, and demonstrate this, through independent assessments or by critical analyses carried out by senior management.

This work demonstrated that it is possible to combine the demands of nuclear safety with the demands of organisational sustainability in a single coherent management system. This management system generates high levels of performance in relation to nuclear safety, and generates sustainable results, expressed by institutional, economic, environmental and social values to stakeholders.

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