2015 International Nuclear Atlantic Conference - INAC 2015
São Paulo, SP, Brazil, October 4-9, 2015
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
***ISBN:* 978-85-99141-06-9**

RISK-BASED INSPECTION IN THE CONTEXT OF NUCLEAR POWER PLANTS

Wellington A. Soares, Vanderley de Vasconcelos and Emerson G. Rabello

Centro de Desenvolvimento da Tecnologia Nuclear – CDTN/CNEN
Av. Presidente Antônio Carlos, 6.627
31270-901 Belo Horizonte, MG

Serviço de Tecnologia de Reatores
soaresw@cdtn.br
vasconv@cdtn.br

Serviço de Integridade Estrutural
egr@cdtn.br

ABSTRACT

Nuclear power plant owners have to consider several aspects like safety, availability, costs and radiation exposure during operation of nuclear power plants. They also need to demonstrate to regulatory bodies that risk assessment and inspection planning processes are being implemented in effective and appropriate manner. Risk-Based Inspection (RBI) is a methodology that, unlike time-based inspection, involves a quantitative assessment of both failure probability and consequence associated with each safety-related item. A correctly implemented RBI program classifies individual equipment by its risks and prioritizes inspection efforts based on this classification. While in traditional deterministic approach, the inspection frequencies are constant, in the RBI approach the inspection interval for each item depends on the risk level. Regularly, inspection intervals from RBI result in risk levels lower or equal than deterministic inspection intervals. According to the literature, RBI solutions improve integrity and reduce costs through a more effective inspection. Risk-Informed In-service Inspection (RI-ISI) is the equivalent term used in the nuclear area. Its use in nuclear power plants around world is briefly reviewed in this paper. Identification of practice methodologies for performing risk-based analyses presented in this paper can help both Brazilian nuclear power plant operator and regulatory body in evaluating the RI-ISI technique feasibility as a tool for optimizing inspections within nuclear plants

1. INTRODUCTION

Nuclear Power Plant (NPP) owners have to consider several aspects like safety, availability, costs and radiation exposure during operation of nuclear power plants. They also need to demonstrate to regulatory bodies that risk assessment and inspection planning processes are being implemented in effective and appropriate manner. Used in a general sense, the term risk indicates the likelihood of the occurrence of undesirable events. Risk-Based Inspection (RBI) is a methodology that, unlike time-based inspection, involves a quantitative assessment of both failure probability and consequence associated with each safety-related item.

A RBI program classifies individual equipment by their risks and prioritizes inspection efforts based on this classification. While in traditional deterministic approach, the inspection frequencies and modes are constant, in the RBI approach the inspection interval for each item depends on the risk level. Regularly, inspection intervals from RBI result in risk levels lower or equal than deterministic inspection intervals. According to the literature, RBI solutions improve integrity and reduce costs through more effective inspection.

RBI has its origins in the petroleum industry, involving equipment under high pressure, like vessels, piping, boilers, etc. It is a proactive inspection methodology that uses available quantitative risk information (frequency and consequences) to manage risks. In this approach, results of inspections are used to change inspection frequencies in order to improve safety. The ultimate goal of RBI is to develop a cost-effective inspection and maintenance program that provides assurance of acceptable mechanical integrity and reliability.

Another version of RBI methodology is the so called Risk-Informed (RI) Inspection, a term first introduced by the U.S. Nuclear Regulatory Commission in order to emphasize the link between risk and inspection, but not implying a direct correlation. If Risk-Based Inspection is understood as inspection planned on the basis of information obtained about the risk, then the two terms are synonymous [1].

In-Service Inspection (ISI) is an essential element of defense-in-depth concept, consisting of non-destructive examination as well as pressure and leakage testing. ISI helps to guarantee that the basic nuclear safety functions are preserved and that the probability of radioactive materials breaching the containment is reduced. Risk-Informed In-Service Inspection (RI-ISI) reflects recent developments in Probabilistic Safety Assessment (PSA) technology, the understanding of degradation mechanisms (e.g. structural reliability modeling, root cause evaluations) and the experience gained from nearly 10,000 reactor years of operating experience by NPPs. RI-ISI is aimed at rational plant safety management by taking into account the results of plant-specific risk analyses. The fundamental idea is to identify high-risk locations where inspection efforts should be concentrated. In other words, the principle underlying RI-ISI is that inspections will be performed where they give the largest safety benefit. This is, at least in principle, applicable to the RPV as well as to piping [2].

Is underway a partnership work involving researchers from two nuclear institutes of the Brazilian nuclear regulatory body (CNEN) in the project "Research and Development in Regulatory and Safety Activities" that makes part of a bigger project supported by the research-sponsoring institution – FINEP, named "Actions of R&D&I and training focused on the resumption of Brazilian Nuclear Program”. A software system with a specific module for Risk-Based Inspection (RBI) is planned to be bought inside this project. This was one of the motivations to start improving the knowledge on Risk-Base Methodologies.

The present paper is focused only on basic concepts of Risk-Based Inspection. However, some important publication pointing out countries that uses RI-ISI are cited as well as main literature on RBI/RI-ISI.

2. THE IMPORTANCE OF RISK-BASED INSPECTIONS

During operation, equipment and systems deteriorate over time, thus increasing the possibility of an accident happening. Therefore, it can be said that risk of an accident increases with time; that is, risk is time-dependent. The question to be answered is: How long can the risk increase? In order to assure safety, a given level of risk is defined as a limit not to be exceeded. Monitoring equipment degradation by inspections is then necessary to find out if this level has not been exceeded.

Traditionally, such monitoring are regularly made by inspections, with fixed time intervals as illustrated in Figure 1, based on manufacturer instructions or on rules stated by regulatory bodies that have licensed the plant in which such equipment is being used. This kind of inspection is known as Time-Based Inspection, considered a reactive methodology.

By usage and ageing, equipment degradation occurs and can be measured in terms of corrosion, thickness reduction of parts or even presence of cracking. Such degradation is dependent on environmental and working conditions to which equipment is submitted and can vary from one facility to another. It means that a same equipment in distinct facilities could require different inspection time intervals. Improvements to take into account such uncertainties have resulted in risk-based methodologies.

Risk-Based Inspection (RBI) is one of such methodologies and uses available quantitative risk information (frequency and consequences) to manage risks. In this case, results of inspections are used to change the inspection intervals in order to improve safety. If RBI is then followed by corrective maintenance, it is possible reduce the risk, which is important for safety.

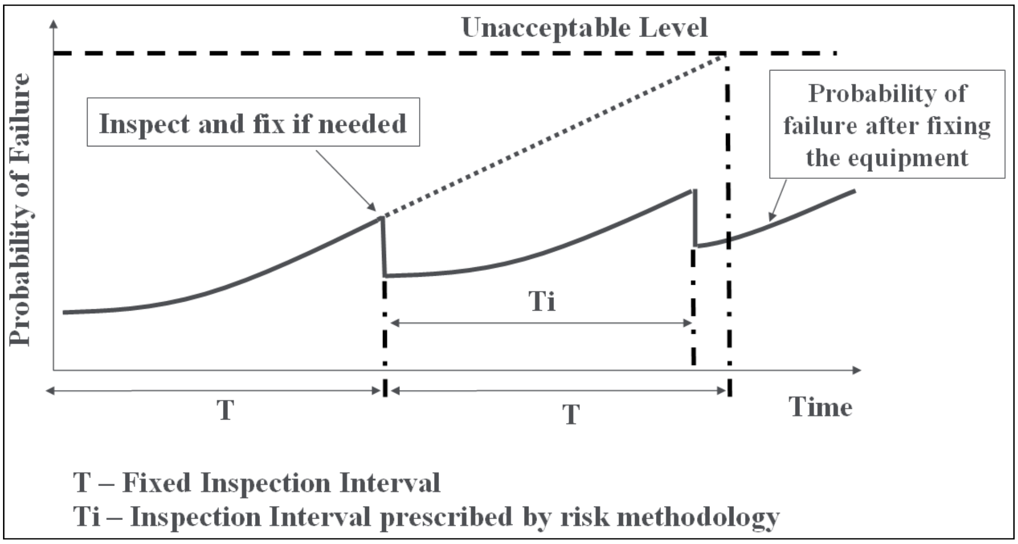

Figure 1: Monitoring equipment failure (Adapted from [3]).

Identification and quantification of material degradation like corrosion, thickness reduction and cracking can be done using non-intrusive techniques. Non-destructive examination is an example of such techniques used to characterize equipment degradation in order to provide assessment of corrosion or other damage mechanisms without the necessity of stopping the process or system in which the equipment is inserted.

As also illustrated in Figure 1, if the fixed inspection interval would be adopted, with no fixing measures, the equipment could reach or even exceed the unacceptable level of Probability of Failure (PoF), before reaching the second prescribed inspection. If however, the second inspection would be done in a smaller time interval (T_i) then PoF would not exceed such unacceptable level. This illustrates the importance of risk-based methodologies that helps to indicate best T_i to be used and also to help managing best performance of the equipment.

Risk-based inspection involves the planning of an inspection based on information obtained from a risk analysis of the equipment. The purpose of the risk analysis is to identify the potential degradation mechanisms and threats to the integrity of the equipment and to assess the consequences and likelihood of failures. The inspection plan can then target the high risk equipment and be designed to detect potential degradation before fitness-for-service could be threatened [1].

Inspection planning concerns the identification of: what, how, where and how often to inspect. Even though inspection may be used as effective means for controlling the degradation of the considered engineering system, implying in a potential benefit, they also have considerable impact on the operation of the system and other economical consequences themselves. For this reason, it is necessary to plan the inspections such that a balance is achieved between the expected benefit of the inspections and the corresponding economical consequences implied by the inspections themselves [4].

Inspection provides new information about the condition of the equipment. This may be the same as previously estimated, but the effect is to reduce the prior uncertainty. New information can therefore change the estimated probability of failure.

An impending failure and its consequences are not prevented or changed by risk-based inspection unless additional mitigating actions are taken. Inspection is an initiator for actions such as the repair or replacement of deteriorating equipment, or a change to the operating conditions. By identifying potential problems, risk-based inspection increases the chances that mitigating actions be taken, and thereby reduces the frequency of failure [1].

3. MATERIAL DEGRADATION

Deterioration processes such as fatigue crack growth and corrosion will always be present to some degree on equipment or systems. Depending on the adapted philosophy in terms of degradation allowance and protective measures, the deterioration processes may reduce the performance of the systems beyond what is acceptable. In order to ensure that the given acceptance criteria are fulfilled throughout the service life of the engineering systems, it may be necessary to control the development of the deterioration and if required to install corrective maintenance measures. In usual practical applications, inspection is the most relevant and effective means of deterioration control [4].

Reference [5] presents the Table “Characterization of the knowledge base on relevant active damage mechanisms for class 1 and 2 components of LWRs”. For each damage mechanism, the following items are listed: component affected; material affected; plant condition; potential impact; governing variables; controllable variables and principal characteristics. Example of damage mechanism cited in that Table are: mechanical fatigue; corrosion fatigue; wear; intergranular stress corrosion cracking; transgranular stress corrosion cracking; irradiation assisted stress corrosion cracking; stress induced corrosion cracking; flow-accelerated corrosion. As potential impact are listed: reduced toughness; cracking; wall thinning; leak and rupture.

Reference [6] brings the Table “Major components of nuclear power plants with PWR and their degradation mechanisms”. Correlations with mechanisms of degradations like corrosion cracking under stress, corrosion fatigue, thermal fatigue and mechanical wear for several components are presented in that Table.

Different deterioration processes will follow different patterns both time wise and in terms of location in the facility depending on the choice of materials, detailing of the structures and process systems, production characteristics, loading and exposure to aggressive environments. The consequence of component failure e.g. in terms of potential loss of lives or costs will depend on the component and its importance for the operation of the facility [4].

4. RBI IN THE CONVENTIONAL INDUSTRY

API RP 581 [7], Risk-Based Inspection Technology, is a recommended practice developed and managed by the American Petroleum Institute (API). Originally released in 2000 and last updated in 2008, the purpose of this publication is to provide quantitative risk-based inspection methods that support the minimum general guidelines presented by API RP 580 [8]. This guideline details the procedures and methodology of RBI, an integrated methodology that uses risk as a basis for prioritizing and managing an in-service equipment inspection program by analyzing both the probability of failure and the consequence of failure.

Figure 2 illustrates risk evolution when using traditional inspection program and when using a RBI approach. Risk reduction can be seen when the second approach is used. This graph itself is a motivation for improving the understanding of this methodology. Of course, risk cannot be reduced to zero due to human errors, natural disasters, design faults, etc. In this Figure, Uninspectable Risk is a residual risk that will always be present.

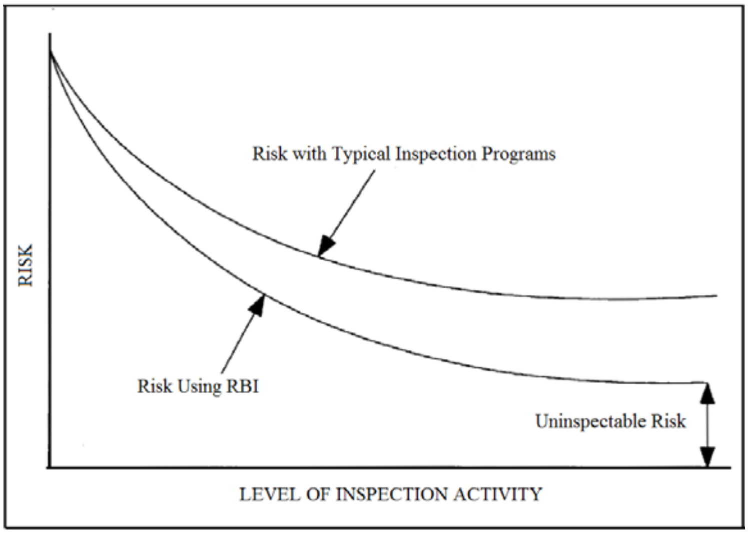

Figure 2: Management of Risk Using RBI [7].

RBI is used to identify and understand risk drivers in order to prioritize inspection-related activities, usually by means of non-destructive examination (NDE), to reduce the uncertainties around the true damage state of the equipment and the dynamics leading to such. The resulting inspection plan outlines the type and scheduling of inspection for an asset. In addition to NDE, additional risk mitigation activities identified by a RBI assessment might include a change in material of construction, installation of corrosion resistant liners, operating condition changes, injection of corrosion inhibition chemicals, etc. [8].

In the Petrochemical and Petroleum Industries, RBI focuses risk assessment on maintaining integrity by minimizing the risk of damage on static equipment such as: pressure vessels, process piping including safety valves and other piping components, atmospheric storage tanks, pressurized storage tanks, boilers, heaters and furnaces, heat exchangers.

5. FUNDAMENTALS OF RISK-BASED INSPECTION

Risk-Based Inspection is a combination of technologies providing industries with a risk-based method for evaluating and developing inspection plans. RBI works by calculating both the consequences of possible failures and the likelihood of those failures. The combination of these two factors identifies which equipment warrants the most attention for managing risk. RBI is therefore a tool to first select which items require attention and then plan when and how to inspect the component or system. As a rule of thumb, 80% of the risk is caused by only 20% of the equipment. It is therefore essential that these high risk components are identified beforehand [9].

5.1 Risk Assessment

Risk is the chance of something (usually negative) happening that will have impact upon objectives. Risk is then the combination of the probability of an event occurs in a period of interest with the result associated with this event. Mathematical risk can be calculated as a product of the two terms: probability of failure and the consequence of such failure. Figure 3 illustrates risk displayed as these two terms on a plot.

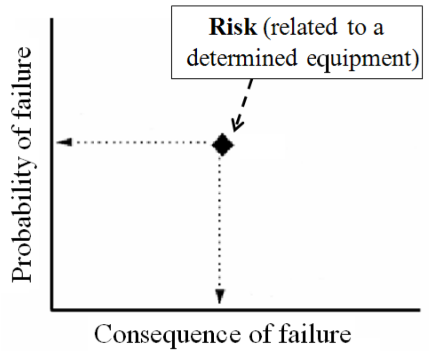

Figure 3: Risk definition in graphical form.

Once the equipment risk is known and an acceptable risk criterion established, risk management has to be conducted. It should be pointed out that risk reduction is not a synonymous for risk management: the reduction is only part of risk management. Risk reduction is the act of mitigating a known risk, considered very high or above the risk criteria, for an acceptable level. On the other hand, risk management is a method for assessing the risk, verifying if risk reduction is necessary and developing a plan for maintaining risk in acceptable levels. Some risks could be identified as low and no mitigation measure will be required. Figure 4 summarizes steps necessary for implementing a RBI project.

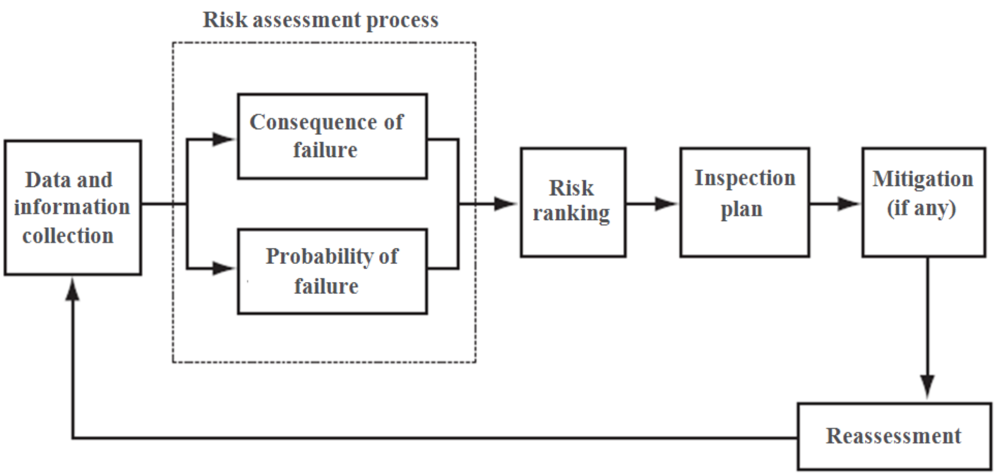

Figure 4: Risk-Based Inspection Planning Process [8].

Both the probability of failure and their possible consequences can be previously estimated, quantitatively and qualitatively, depending on the considered system characteristics and the data available for evaluation. Thus, the risk assessment can be classified as quantitative, qualitative or semi-quantitative. Thus, the larger the volume of data accessible, less subjectivity will be the analysis and results with greater accuracy will be obtained [8].

5.2 Failure Probability Assessment

According to [8], the probability of failure which must be used in a RBI approach is the probability of a specific consequence resulting from failure of one or more equipment that occurs due to some damage mechanism. Therefore, the probability to be evaluated is not only the probability of equipment failure itself, but product of the probability of other events that follow upon failure of the equipment before the final consequence. It means that equipment failure event may be the first in a series of events that lead to a specific consequence, and therefore the probability of these other events should be considered.

5.2.1 Qualitative Assessment

A qualitative assessment involves the identification of units, systems or equipment, building materials and corrosive components of the processes. Based on knowledge on history of operation, inspection and future plans for maintenance and possible deterioration of materials, the PoF can be evaluated separately for each unit, system, equipment group or item of equipment. Then PoF category can be assigned to each system unit, group or item of equipment. Depending on the methodology, the categories can be described with words (such as high, medium or low) or may have numerical descriptors (such as 0.1-0.01 times per year) [8].

5.2.2 Quantitative evaluation

Several approaches are available for performing the quantitative analysis of probability of failure. A specific example is collecting failure data and their respective occurrence in order to get samples of such these events over time. It is then possible to obtain models of continuous distribution of probability over time. The most commonly used probability distributions are exponential and Weibull [8]. Another approach is used when the failure data are inaccurate or nonexistent for the equipment in which we are interested. In this case, failure data are used from industry or from manufacturer. Such data should be adjusted according to the damage mechanisms of present in the equipment as well conditions and severity in which they operate. Thus, the general failure data are used to generate an adjusted frequency for the equipment in a specific application [8].

5.3 Assessment of Failure Results

The analysis of consequence should be a repeatable, simplified and reliable estimation of the scenario expected to happen if a failure occurs in the evaluated equipment. Such analysis should be conducted to estimate the consequences of a typical failure mode resulting from the damage mechanism identified [8]. Failure consequences are classified as: a) health and safety impacts; b) environmental impacts; c) economic impacts.

5.3.1 Qualitative Assessment (Risk categorization)

A qualitative assessment involves identifying the units, systems or equipment, as well as the risks present as a result of operating conditions and other correlated process. Based on the technical knowledge and experience, the consequences of failure (safety, health, environmental and financial impacts) can be estimated separately for each unit, system, equipment group or individual item of equipment. In a qualitative assessment, a category of consequences (such as "A" to "E" or "high", "medium" or "low") is typically assigned to each unit, system, group of equipment or item of equipment [8].

5.3.2 Quantitative Assessment

A quantitative assessment involves the use of a logical model representing combinations of events in order to show the effects of failures on people, property, the company and the environment. Its application is only possible when the consequence of failure is something countable. For instance financial loss, number of deaths, affected area, etc. [8].

Companies usually adopt risk acceptance criteria in the following contexts: financial, environmental and health and safety of its workforce. This criterion should be used in an RBI approach, increasing the safety factor on a local evaluation, but never less conservative than the corporate criteria.

5.4 Acceptability Criteria and Failure Risk Presentation

Since the risk values are assessed, they may then be presented in a variety of ways to transmit the analysis results. One of the risk analysis goals is to communicate the results in a common format that a variety of people can understand. For this purpose, it recommended to present results in a risk matrix or in a risk graph. These tools make possible to join information on probability and consequence of failure, besides the risk acceptance criteria, in order to provide an integrated evaluation of the equipment in a plant [8].

5.4.1 Risk Matrix

Methods for risk classification use probability categories and/or probability consequences, i.e. in a qualitative or semi-quantitative risk assessment, a risk matrix should be used. The reason is that it provides an effective way of presenting the distribution of risk across the entire plant or process without numerical values. A risk matrix example is shown in Figure 5, where categories of consequence and probability are organized in such a way that the greatest risk position is toward the upper right corner. Different array sizes can be used (e.g. 5x5, 4x4, etc.). Regardless of the selected matrix, the categories of consequence and probability should provide sufficient discrimination between the evaluated items [10].

Risk categories can be assigned to the boxes in the risk matrix. A risk categorization example (higher, medium, lower) in the risk matrix is also shown in Figure 5, where risk categories are symmetrical. They may also be asymmetric where, for example, if to the consequence category be given greater weight than to the category probability.

The question now is what to do with such categories. According to [10] the following actions, illustrated in Figure 6, should be followed from the analysis of RBI results:

- if the probability of failure is low, inspection will have no effect in further reducing the risk;
- if the consequence is also low, then the recommended action is minimum surveillance;
- if the probability of failure is low but consequence is high, preventive maintenance should be considered to control the risk;
- if probability is high but consequence is low risk corrective maintenance is recommended;
- where both probability and consequences are high, detailed RBI is required.

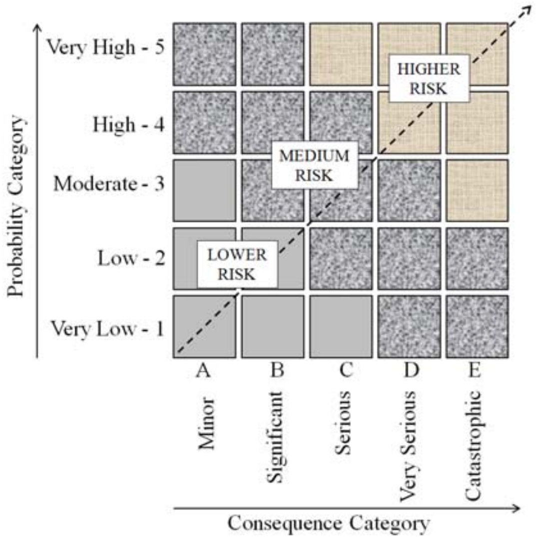

Figure 5: Example of a qualitative risk matrix.

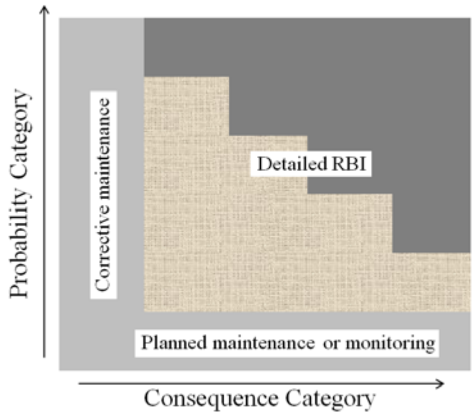

Figure 6: Risk screening matrix [adapted from 10].

5.4.2 Risk Graph

A risk graph is used when both probability and consequence quantitative data are used and where to show numerical risk values is more significant for those interested. Just as the risk matrix, this chart is constructed so that the greatest risk is drawn toward the upper right corner. Often risk graph is shown in a logarithmic scale for better evaluation of the risks obtained. In Figure 7, an example risk for ten equipment of a plant is illustrated, as well as a iso-risk line (constant risk line). If this line is the acceptable risk limit, then equipment items 1, 2 and 3 should be mitigated, so that the resulting risk levels fall below the line.

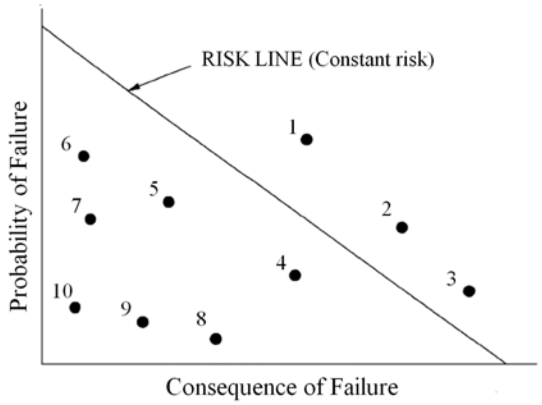

Figure 7: Illustration of risk associated with the operation of 10 equipment items in a process plant (Adapted from [8]).

6. RBI IN NUCLEAR POWER PLANTS

In the 1900s, a first guideline on Risk-Based Inspection for Light Water Reactor (LWR) components was published as a result of the ASME Research Task Force on Risk-Based Inspection Guidelines [11], demonstrating the engagement of the nuclear area in such methodology.

In Risk-Informed (RI) Inspection, a more recent version of RBI, the terminology "Informed" is used to emphasize the link between risk and inspection. RI characterizes an approach, where insights from risk assessment are considered together with other factors to make integrated decisions: a probabilistic risk assessment [11].

Risk-Informed In-service Inspection (RI-ISI) is the term that has been used in the publications from the nuclear area.

Table 1 summarizes countries involved with RI-ISI methodologies focused on nuclear power plants, based on IAEA Nuclear Energy Series, a specific publication for NPP piping systems [12]. In reference [11], focus is given on RI-ISI of piping, because this is at present the major area of application and the scope of the existing methodologies and procedures. In the cited Nuclear Energy Series, a complete description of each approached methodology is given.

Table 1: Countries using the RI-ISI methodology [12].

Status	Country	Used methodologies	Description of activities
Applications	Bulgaria	PWROG	Partial scope application of PWROG methodology
	Finland	RI-ISI	Full scope RI-ISI projects under way (Loviisa WWER-440 & Olkiluoto BWR), using similar risk matrix as in EPRI methodology, but not following exactly the methodology
	Mexico	EPRI	EPRI application in process (Laguna Verde BWR), class 1&2
	Republic of Korea	PWROG	Class 1 and 2 applications of PWROG methodology
	South Africa	EPRI	Application of EPRI methodology (Koeberg PWR), class 1&2
	Spain	RI-ISI, PWROG	Several applications for RI-ISI programs have been approved for class 1 piping systems (PWROG)
	Sweden	PWROG, SKIFS	Ringhals has applied PWROG methodology, approval process not completed yet. All Swedish plants have ISI program based on SKIFS 1994:1
	USA	EPRI, PWROG, Other	EPRI methodology: 68 plants PWROG methodology: 17 plants EPRI & PWROG methodology: 5 plants Other methodologies: 2 plants No RI-ISI: 11 plants Note: of the above, 16 are transitioning to the EPRI Streamlined RI-ISI approach (5 EPRI, 5 Westinghouse, 6 None)
Pilot studies	Czech Republic	EPRI	EPRI pilot studies, several systems in Temelin (WWER-1000) and Dukovany (WWER-440)
	France	OMF	OMF structures methodology piloted to 12 systems
	Lithuania	NURBIT RI-ISI	NURBIT RI-ISI approach pilot
	Slovakia		Application under way, future steps dependent on pilot study results
	Sweden	NURBIT RI-ISI	Oskarshamn and Forsmark pilot studies using NURBIT RI-ISI approach
		EPRI	Pilot Study under way at Forsmark, Unit 3 using EPRI methodology
	Switzerland	EPRI, PWROG	EPRI pilot study at Leibstadt, PWROG pilot study at Beznau
	Ukraine	EPRI	EPRI pilot study at Khmelnitsky WWER-1000
Other	Belgium	RISMET	Participating in international activities (e.g. RISMET)
	Japan	RISMET	Some activities taking place (e.g. RISMET)
	Taiwan (China)		Some activities taking place

Notation for Tables 1 and 2:

ASME - American Society of Mechanical Engineers
EPRI- Electric Power Research Institute
EURIS- European Network of Risk informed In-service Inspection
ISI - In-Service Inspection
IAEA – International Atomic Energy Agency
NRC – U.S. Nuclear Regulatory Commission
NURBIM - Nuclear Risk-Based Inspection Methodology
NURBIT - Nuclear Risk-Based Inspection Tool
OMF- Optimization of maintenance for structures
PWROG - PWR Owners Group
RI - Risk-Informed
RI-ISI - Risk-Informed In-Service Inspection
RISMET - RI-ISI Methodologies
RISMET- RI-ISI Methodology benchmark project
SKIFS - Swedish Nuclear Power Inspectorate's Regulations
VTT - Technical Research Centre of Finland
WOG - Westinghouse Owners Group

Table 2 summarizes main information on two relevant RI-ISI documents applied to NPP piping systems: IAEA Nuclear Energy Series [12, 14], USNRC Regulatory Guide [13] and OECD [15].

Table 2: RI-ISI reference documents for nuclear power plants.

Document Title	Document Nature	Applicability	Approached Methodologies	Date
Risk-informed In-service Inspection of Piping Systems of Nuclear Power Plants: Process, Status, Issues and Development	IAEA Nuclear Energy Series - No. NP-T-3.1 [12]	Piping Systems of Nuclear Power Plants	a) EPRI Methodology b) PWROG Methodology c) ASME Code Case N-716 d) Optimization of maintenance structures e) SKIFS Methodology f) RI-ISI approach for the Lovisa II Nuclear Power Plant	2010
An Approach for Plant-Specific Risk-Informed Decisionmaking for In-service Inspection of Piping	Regulatory Guide 1.178 – NRC [13]	Piping at a nuclear power facility	a) EPRI TR-112657 - Electric Power Research Institute b) WCAP-14572 - WOG)	Revision 1 September 2003
Improvement of in-service inspection in nuclear power plants	IAEA-TECDOC-1400 [14]	Strategies for improving the effectiveness of ISI	-	July 2004
Applications concerning OECD Pipe Failure Database OPDE	Research Report VTT-R-00416-11:Finland [15]	Nuclear power plant piping system	-	April 2011

According to [12], NURBIT, WinPRAISE and PRODIGAL are the most commonly used programs for nuclear piping.

Some relevant information on in-service inspection can be found on references [16] to [19].

6. CONCLUSIONS

The fundamental idea of Risk-Based Methodologies is to identify high-risk locations where inspection efforts should be concentrated. In other words, the principle underlying such approaches is that inspections will be performed where they give the largest safety benefit.

Both Risk-Based Inspection and Risk-Informed Inspection quantify risk based not only on a component, but considering all components on the facility as a whole. Different inspection strategies with different inspection effort, inspection quality and costs will have different effect on the risk.

Risk-Based Methodologies are methods for optimizing in-service inspection activities and also an alternative to conventional time-based inspection. However, in the literature it is reported that such techniques only work when they are accompanied by other methods and assumptions about how things related to the world of engineering failure, analysis, and inspection actually work. All these supporting assumptions are necessary if success is desired.

Main of the available consulted literature on RBI in the nuclear area is focused on nuclear piping systems. Some countries have already effective RBI applications, while others have pilot studies or are involved with related subjects.

Requirements for risk management by RBI are established within the context of existing regulations, inspection codes and practices. Despite Probabilistic Safety Assessment (PSA) has been carried out in Angra 3 Nuclear Reactor, up to now no guideline concerning RBI or RI-ISI technique was published by the Brazilian nuclear regulatory body. The results of the survey on RBI concepts and uses presented is this paper can provide an opportunity to integrate both Brazilian nuclear power plant owners and Brazilian nuclear regulatory body in a discussion on this theme.

ACKNOWLEDGMENTS

The authors would like to thank the following institutions, which sponsored this work: CDTN/CNEN (Centro de Desenvolvimento de Tecnologia Nuclear/Comissão Nacional de Energia Nuclear), FINEP (Financiadora de Estudos e Projetos) and FAPEMIG (Fundação de Amparo à Pesquisa do Estado de Minas Gerais).

REFERENCES

1. HEALTH AND SAFETY EXECUTIVE, "Best practice for risk based inspection as a part of plant integrity management", *Contract Research Report 363/2001*, Norwich, (2001).
2. EUROPEAN NETWORK FOR INSPECTION AND QUALIFICATION, "ENIQ TGR Discussion document on the role of in-service inspection of the reactor pressure vessel", *ENIQ Report No 35*, EUR 23419/EN, August, (2008).
3. J. Daarud, "Risk-Based Inspection Program Best Practice", LLOYD'S REGISTER ENERGY CANADA LIMITED – LREC, Texas, USA, http://blog.lrenergy.org/wp-content/uploads/2013/10/2-Daarud-RBI-Program-Best-Practices.ppt.
4. M. H. Faber, "Risk Based Inspection – the Framework", *Proceedings of the International Workshop Risk Based Inspection and Maintenance Planning*, Zürich, Swizerland, December 14-15, 2000, **Vol. 1**, pp.5-23, (2001).
5. H. Schulz1, T. Schimpfke, R. Axelsson, B. Brickstad, O. Chapman, J.B. Wintle, C. Faidy, C. Cueto-Felgueroso, W. Kohlpaintner, A. Saarenheimo, B. Shepherd, L. Horacek, A. Eriksson, "Nuclear Risk-Based Inspection Methodology for passive components", ftp://ftp.cordis.europa.eu/pub/fp5-euratom/docs/fisa2003_2-5_nurbim_en.pdf.
6. G. Arkadov, A. Getman, A. Rodionov, *Probabilistic Safety Assessment for Optimum Nuclear Power Plant Life Management (PLiM)*, Woodhead Publishing, (2012).

7. AMERICAN PETROLEUM INSTITUTE, “Risk-Based Inspection Technology”, 2nd Edition. *API RP 581*, Washington, DC, EUA, September, (2008).
8. AMERICAN PETROLEUM INSTITUTE, “Risk-Based Inspection”, 2nd Edition, *API RP 580*, November, (2009).
9. M. Kalle, *Risk Based Inspection in the Process and Refining Industry* (Master's thesis), Faculty of Information Technology and Systems, Technical University of Delft, Delft, The Netherlands, December, (2002).
10. J. Goyet, “Integrated Approach for RBI of Offshore Installations”, *Proceedings of the International Workshop Risk Based Inspection and Maintenance Planning*, Zürich, Swizerland, December 14-15, 2000, **Vol. 1**, pp.117-127, (2001).
11. EUROPEAN COMMISSION, “Regulatory Experience of Risk-Informed In-service Inspection of Nuclear Power Plant Components and Common Views”, *Final Report EUR 21320EN*, Working Group Task Force on Risk-Informed Inservice Inspection, (2004).
12. INTERNATIONAL ATOMIC ENERGY AGENCY, *Risk-informed In-service Inspection of Piping Systems of Nuclear Power Plants: Process, Status, Issues and Development*, Nuclear Energy Series No. NP-T-3.1, IAEA, Vienna, (2010).
13. NUCLEAR REGULATORY COMMISSION, *An Approach for Plant-Specific Risk-Informed Decisionmaking for Inservice Inspection of Piping*, Regulatory Guide 1.178, USNRC, September (2003).
14. INTERNATIONAL ATOMIC ENERGY AGENCY, *Improvement of In-Service Inspection in Nuclear Power Plants*, IAEA TECDOC- 1400, Vienna (2004).
15. O. Cronvall, I. Männistö, “Applications concerning OECD Pipe Failure Database OPDE”, *Research Report VTT-R-00416-11*, Finland, (2011).
16. INTERNATIONAL ATOMIC ENERGY AGENCY, *Maintenance, surveillance and in-service inspection of nuclear power plants*, Standard Safety Series, No. NS-G-2.6, IAEA, Vienna (2002).
17. EUROPEAN NETWORK FOR INSPECTION AND QUALIFICATION, “ENIQ TGR Discussion document on the role of in-service inspection within the philosophy of defense in depth”, *Report No 29*, EUR 22230/EN, The Netherlands (2007).
18. D. Papasalouros, K. Bollas, D. Kourousis, N. Tsopelas, A, Anastasopoulos, “Modern Inspection Methodologies for RBI Programs of Atmospheric Storage Tanks”, *Proceeding of 11th European Conference on Non-Destructive Testing (ECNDT 2014)*, Prague, Czech Republic, October 6-10, (2014).
19. P. O’Regan, J. Moody, J. Lötman, J. Sandstedt, “Using the EPRI Risk-Informed ISI Methodology on Piping Systems in Forsmark 3”, *Report number: 2010:42*, Swedish Radiation Safety Authority, December, (2010).