Website: http://www.sresa.org.in

SRESA Newsletter

April 2012 / Issue No. 6

Quarterly publication from Society for Reliability and Safety [Reg. No. 3141/2010/G.B.B.S.D.]

New

From the President's Desk

The Society for Reliability and Safety is striving to meet its objective of knowledge sharing and bringing together leading academics, industry, and research in the field of Reliability, Safety, Security, Risk and Maintenance in Engineering systems and to establish and strengthen the link between academics and industry, to promote of research results in practice. This is the sixth issue of this newsletter, which announces the launch of the International Journal of Life Cycle Reliability and Safety Engineering. This journal provides a medium to researchers and academicians to contribute articles based on their work. Society of Reliability & Safety is thus quarterly publishing a journal along with this newsletter. This issue contains four articles. The first one deals with the passive system reliability assessment of nuclear power plants. Issues related to evaluation of passive system reliability have been discussed. An article discusses the maintenance issues that need attention in the Defence Department, and type of problems faced by the maintainers on field. The research work presents a method to model the failure and wear/deterioration processes.

A brief note on two workshops are present; 1) ' ISEUSAM 2012' was to facilitate the discussion for a better understanding and management of uncertainty and risk. 2) An International Workshop on 'New Horizons in Nuclear Reactor Thermal Hydraulics and Safety'. Developments and future challenges in different areas related to nuclear reactor thermal hydraulics especially on severe accident, emergency preparedness, and safety were discussed.

Dr. S. K. Gupta

Inside this issue:

Reliability Analysis of Passive Systems Using APSRA Methodology

A.K. Nayak, Reactor Engineering Division, Bhabha Atomic Research Centre, Trombay, Mumbai - 400085, India
arunths@barc.gov.in

1. Introduction

Advanced nuclear reactor designs incorporate several passive systems in addition to active ones, not only to enhance the operational safety of the reactors but also to eliminate the possibility of hypothetical severe accidents. Unlike the active systems, the passive system does not need external input such as energy to operate. Passive systems are simpler in design besides avoiding human intervention in their operation, which increases their reliability as compared to the active ones. However, their performance is always correlated with the system geometry and the operating parameters. Normally, the driving head of passive systems is small, which may be easily influenced even with a small change in operating condition. This is particularly true for the passive systems classified as "Type B" by IAEA [1], i.e. those with moving working fluid; for example a natural circulation system. Such systems rely on natural forces arising due to gravity or buoyancy. The driving force is created by the buoyancy action due to change in density of fluid across the heated/cooled sections. Its magnitude can be easily altered due to any disturbance either in operating parameters or geometry. Because of this, there has been growing concern amongst the nuclear engineers about their reliability not only at normal operation but also during transients and accidents.

2. Evolution of State-of-Art methodologies

The pioneering step in the direction of passive system reliability assessment was the development of REPAS [2] as cooperative effort by ENEA, the University of Pisa, the Polytechnic of Milan and University of Rome. This methodology was based on the evaluation of a failure probability of a system to perform its desired function from the epistemic uncertainties of the parameters which can cause the failure of system. This methodology has been applied to an experimental natural circulation loop [3] and for reliability evaluation of an isolation condenser system [4]. The methodology was later refined and led to the evolution of RMPS under fifth framework programme of the EU [5]. The RMPS approach is based on adopting a probability density function to the critical variables affecting the system performance and propagating the uncertainties of variables in the thermal-hydraulic models. Similar approach was followed to evaluate the failure probability of the natural circulation system of the gas cooled fast reactor [6].

Another notable development in this direction was the evolution of APSRA methodology [7]. This methodology is based on the generation of failure surface based on the variation of critical process parameters. The methodology attributes variation of the critical process parameters from their nominal values to the failure of active components or control and instrumentation systems which maintains the parameters at their nominal states. Thus the methodology dispenses away the treatment of assumed probability density function for variation of critical process parameters. Besides, the methodology treats the code uncertainty by comparing the code predictions with the test data. Applications of this methodology has been demonstrated for passive systems of AHWR like natural circulation in the main heat transport system, isolation condenser system to remove decay heat [8] and passive containment isolation system [9].

3. The APSRA methodology

In the APSRA methodology, the passive system reliability is evaluated from the evaluation of the failure frequency of the system to carry out the desired function. This is a hierarchical step-wise methodology. A detailed discussion of the APSRA methodology is given in the following section.

Step I: Passive System for which reliability assessment is considered

In step I, the passive system for which reliability will be evaluated is considered.

Step II: Identification of parameters affecting the operation

The performance characteristic of the passive system is greatly influenced by some process parameters. For example, some of the process parameters which influence the natural circulation flow rate in a boiling two-phase natural circulation system are system pressure; heat addition rate to the coolant; water level in the steam drum; feed water temperature, presence of non-condensable gases;

Step III: Operational characteristics and failure criteria

In step III, APSRA requires the designer to have a clear understanding of the operational mechanism of the passive system and its failure, i.e. characteristics of the passive system. To judge its failure, the designer has to define its failure criteria. The characteristics of the system can be simulated even with simpler codes which can generate the passive system performance data qualitatively in a relatively short period. In this step, the purpose is just to understand the system operational behaviour but not to predict the system behaviour accurately. For this the designer has to use the parameters identified in Step II, which can influence on the performance of the system. Out of them, some must be critical in the sense that a disturbance in these parameters can lead to a significant change in the performance of the system, while others do not. Only a thermal hydraulic expert can judge this behaviour through parametric calculations. This step further requires prescription of failure criteria of the system. For example, in a natural circulation system, the natural circulation flow rate may not be sufficient to fulfil the desired objectives of the system, which can be inadequate removal of core heat causing rise in clad surface temperature; or occurrence of flow oscillations which are undesirable for operation of plant; or occurrence of CHF with or without flow oscillations, etc. The system designer may consider the system to fail if any of these criteria are met.

Step IV: Key parameters which may cause the failure

The studies in Step III and Step IV are complimentary to each other, in the sense that while the results of step III help in understanding the performance characteristics of the system due to variation of the critical parameters, step IV generates the results for those values of the critical parameters at which the system may fail.

Step V: Generation of failure surface and validation with test data

Once the key parameters are identified in Step IV (deviation of which can cause the failure of the system), the values of these parameters at which the system will fail, are calculated using a best estimate code. Hence there is another requirement for Step V, i.e. the results should be generated using a best estimate code in order to reduce the uncertainty in the prediction of the failure conditions. The results of Step IV generated using a simpler code is only useful in directing the inputs for Step V in order to derive the failure conditions rather quickly. Since applicability of the best estimate codes to passive systems are still not well established, APSRA requires experimental data for validation of codes used for simulation of passive systems performance and failure.

Step VI: Root diagnosis to find deviation of key parameters for causing ultimate failure of system

After establishing the domain of failure, the next task is to find out the cause of deviation of key parameters which eventually result in the failure of the system. This is done through a root diagnosis method. For example, a reduction in core inlet sub-cooling in natural circulation reactor can be due to reduction of feed water flow rate. This can happen due to partial availability of the feed pumps; malfunctioning of feed control valves or controller, malfunctioning of steam drum level control valves; etc.

A passive system fails to carry out its function not due to failure of its mechanism, but definitely due to deviation of some of the process parameters on which its performance depends. These so called "key parameters" deviate from their nominal values due to failure of either some active components such as a control valve, or an external pump, or electric signal, or control and instrumentation systems, etc.; or due to failure of some passive components such as a passive valve, or a relief valve, etc. For evaluation of reliability of the system at normal operational transients, failure of components such as a pipe leading to LOCA should not be considered, unless one considers the corresponding failure criteria for LOCA condition.

Step VII: Evaluation of failure probability of components causing the failure:

This is the most critical step in evaluation of reliability of the system. Once the causes of failure of key parameters are known in Step VI, the failure probability of the components can be evaluated using the classical PSA treatment through a clean event/fault tree analysis.

4. Critical issues in passive system reliability analysis

Probabilistic treatment of critical parameters

The early developed methodologies like REPAS and RMPS are based on consideration of a probability density function (pdf) for treatment of variation of different parameters affecting the system performance, which include process parameters, geometric parameters and model uncertainties. Consideration of a pdf to accommodate the variability of geometrical parameter or material properties may have rationale and established basis. However, importing the same logic to incorporate the variability of process parameter like pressure or water level in steam drum seem untenable as its does not have a physical basis though it is readily amenable to mathematical treatment. This is because these parameters in true sense, are not independent parameters to have their variation or deviation randomly. They are controlled with the help of certain control system and they deviate from their nominal values if the active components or systems which control them fail. In view of this, statistical treatment using probabilistic distribution particularly for the interdependent operating parameters deserves serious attention in context of passive system reliability assessment.

Another problem plaguing the reliability assessment of passive system is the treatment of parameters in time domain i.e. application of generic failure frequencies with due consideration of mission time. As it is well understood that the failure of passive system can always be traced to the failure of active components / systems like associated controllers, valves, and pumps etc., which lead to degraded conditions of process and reduced driving force. This allows for assessment of passive system reliability on the basis of failure frequencies of such active components. The failure frequencies of such components are generally associated with the concept of binary state , for example, a valve that fails to open can have fully open state as success and all other states as failure. However, in practice, a partially open valve may not lead to a failure of the passive system depending on the grace period available. For the shorter mission times, even a partially open valve may lead successful performance of passive system. In light of this, it appears that, a rational and acceptable method of reliability assessment of passive systems must consider the multiple states of active components.

Uncertainty Associated with Best Estimate Predictions

In absence of adequate operational experience with passive systems, it is customary to depend on the prediction of their performance using best estimate codes. The applicability of best estimate codes to model such systems and capture the various phenomena associated with such system is questionable. As a consequence of this, prediction of passive system performance is associated with uncertainties and needs to be resolved to evaluate the reliability of passive systems. The uncertainties due to error between the code prediction and test data in a natural circulation system have not been well established. These uncertainties can significantly influence the prediction of natural circulation characteristics and hence assessment of its reliability.

Validation of Passive System Reliability

Unlike active components such as valves, controllers and pumps, the passive systems are not amenable to isolated testing under simulated conditions in a laboratory because the passive systems can not be decoupled from the associated systems for realistic assessment as their driving force depends on the boundary conditions imposed by associated systems that calls for integral system simulation.

5. Summary

Evaluation of passive system reliability is a challenging task. It involves a clear understanding of the operation and failure mechanism of the system which the designer must do before prediction of its reliability. Besides, applicability of the so called 'best estimate codes' for the reliability of passive systems are neither proven nor understood enough due to lack of sufficient plant/experimental data. That also creates another problem in assessing the uncertainties of the best estimate codes when applied to passive system safety analysis. In this note, a methodology known as APSRA has been discussed which has been used to evaluate the reliability of passive systems. Critical issues related to evaluation of passive system reliability have been highlighted.

References

1. IAEA, "Safety related terms for advanced nuclear plants," IAEA TECDOC-626, 1991.
2. F. D'Auria and G. M. Galassi, "Methodology for the evaluation of the reliability of passive systems," University of Pisa, DIMNP, NT 420, Pisa, Italy, 2000.
3. J. Jafari, F. D'Auria, H. Kazeminejad, and H. Davilu, Nucl. Eng. Des. 224, pp. 79-104, 2003.
4. E. Zio, M. Cantarella, A. Cammi, Nucl. Eng. Des. 226, pp. 311-336, 2003.
5. M. Marqu'es, J. F. Pignatel, P. Saignes, F. D'Auria, L. Burgazzi,, C. M¨uller, R. Bolado-Lavin, C. Kirchsteiger, V. La Lumia, and L. Ivanov, Nucl. Eng. Des. 235, pp. 2612-2631. 2005.
6. L.P. Pagani, G. E. Apostolakis, and P. Hejzlar, Nucl. Technol. 149, pp. 129-140, 2005.
7. A. K. Nayak, M. R. Gartia, A. Antony, G. Vinod, and R. K. Sinha, Nuclear Engineering and Design 238, pp. 1430-1440, 2008.
8. A. K. Nayak, Vikas Jain, M. R. Gartia, Hari Prasad, A. Anthony, S. K. Bhatia, and R. K. Sinha, Reliability Engineering and System Safety, vol. 94, pp. 1064-1075, 2009.
9. A. K. Nayak, Vikas Jain, M. R. Gartia, A. Srivastava, Hari Prasad, A. Anthony, A. J. Gaikwad, S. K. Bhatia, and R. K. Sinha, Annals of Nuclear Energy, vol. 35, pp. 2270-2279, 2008.

International Symposium on Engineering under Uncertainty: Safety Assessment and Management (ISEUSAM - 2012)

In engineering applications, it is important to model and treat adequately all the available information during the analysis and design phase. Typically, the information is originated from different sources like field measurements, experts' judgments, objective & subjective considerations. Over these features, the influence of human errors, imperfections in the construction techniques and production process, influence of the boundary and environmental conditions are added. All these aspects can be brought under one common denominator: that is "presence of uncertainty". Thus, reliability and safety are the core issues which need to be addressed during the analysis, design, construction and operation of engineering systems under uncertainties.

In this backdrop, the aim of ISEUSAM 2012 was to facilitate the discussion for a better understanding and management of uncertainty and risk, encompassing various aspects of safety and reliability of engineering systems. To be specific, the overall theme of the symposium was modelling, analysis, and design of engineering systems and decision making under uncertainties relevant to all engineering disciplines. The ISEUSAM-2012 was organised during January 4 to 6, 2012 at the Bengal Engineering and Science University, Shibpur, Howrah 711 103, West Bengal, India

The proceedings began on a grand scale amidst rousing welcome to the delegates and an overwhelming enthusiasm amongst the organizers and the delegates on January 4, 2012 with the Opening Ceremony. This was followed by a series of Technical Sessions including Plenary Sessions on numerous sub-themes spread over all three days. The symposium was inaugurated by Dr. Rakesh Kumar Bhandari, Director, Variable Energy Cyclotron Centre Kolkata, and presided over by Prof. Ajoy Kumar Ray, Vice-Chancellor, Bengal Engineering and Science University, Shibpur. Prof. Arun Kumar Majumdar, Deputy Director, Indian Institute of Technology Kharagpur was the guest of honour.

The Technical Programme

The conference received an overwhelming response from national as well as international scholars, experts and delegates from different parts of the world. Papers were received from authors from several countries including Australia, Canada, China, Germany, Italy, UAE, UK and USA, besides India. More than two hundred authors have shown their interest in the symposium. Out of this eighty eight papers in the symposium were allotted to the four plenary and twelve parallel sessions. The Plenary sessions comprised the inaugural key-note lecture on the opening day followed by plenary lectures on each of the three days. Such lectures were delivered by the internationally acclaimed experts.

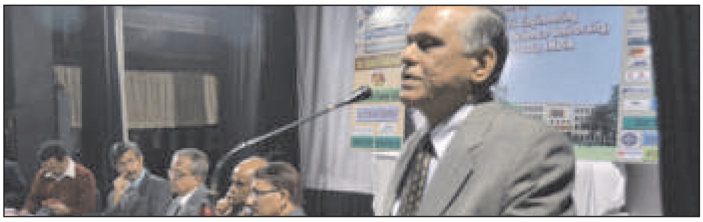
The Technical Sessions

There were altogether 12 Technical Sessions addressing the issue of uncertainty encompassing various fields of engineering i.e. Uncertainty Analysis and Modelling, Structural Reliability, Geotechnical Engineering, Vibration Control, Earthquake Engineering, Environmental, Engineering, Stochastic Dynamics, Transportation System, System Identification and Damage Assessment, Infrastructure Engineering conducted in 6 parallel sessions for each of the three days. Papers presented in each session began with one or two invited theme Paper (s), followed by the Contributory Papers.

The Valedictory Session

The valedictory function of ISEUSAM - 2012 was a fitting finale to the symposium. Dr. Achintya Haldar, Professor and da Vinci Fellow, University of Arizona, who was the Chair, International Scientific Committee and one of the chief architects of the event, admirably summed up the conference proceedings. He also spelt out the future direction of the symposium by mooting a proposal of organizing it on a regular basis. Dr. Milan Kumar Sanyal, Director, Saha Institute of Nuclear Physics, in his role as the Chief Guest, enlightened the audience about the high energy synchrotron project, only the fifth of its kind globally, that is in the pipeline of SINP and expressed his eagerness to collaborate with BESU. Dr. T. K. Datta, Professor Emeritus, IIT Delhi, was the Guest of Honour at the programme. "Death is certain, yet, when is uncertain..." echoed Dr. Datta on a philosophical note and went on to applaud the Department of Civil Engineering, BESU, for putting in such a wonderful effort in organizing this symposium on uncertainty, the first of its kind in India. The Vice-Chancellor of BESU, Prof. Ajoy K. Ray, despite being indisposed, in a remarkable gesture, graced the occasion and was his usual inspiring self. The participants expressed that they had found the sessions truly engrossing and also that they were extremely satisfied with the arrangements. On the whole, the symposium was lauded as hugely successful and memorable academic event.

Compiled by: Prof. Subrata Chakraborty, Organizing Secretary, ISEUSAM-2012



Dr. Rakesh Kumar Bhandari, Director, VECC, Kolkata, delivering his inaugural address

Prof. Ajoy Kumar Ray, VC, BESU, Shibpur, delivering his presidential address

A Technical Session in progress

International Workshop on New Horizons in Nuclear Reactor Thermal Hydraulics and Safety

An International Workshop on New Horizons in Nuclear Reactor Thermal Hydraulics and Safety was organized by Atomic Energy Regulatory Board in co-operation with the Board of Research in Nuclear Sciences (BRNS) and Society for Reliability and Safety (SRESA) at the Convention Center, Safety Research Institute (SRI), Atomic Energy Regulatory Board, Kalpakkam - 603102 during January 2-3, 2012.

The recent developments and future challenges in different areas related to nuclear reactor thermal hydraulics especially on severe accident, emergency preparedness, and safety were discussed.

Dr. S. K. Gupta, Director, SADD, AERB, President, SRESA and Convener, Organising Committee of the workshop welcomed all the dignitaries. Shri S. S. Bajaj, Chairman, AERB inaugurated the workshop and delivered the presidential address. Shri S. S. Bajaj also released the inaugural issue of New International Journal "SRESA's International Journal of Life Cycle Reliability and Safety Engineering".Shri S. C. Chetal, Director, Indira Gandhi Centre for Atomic Research, Kalpakkam made the opening address. He stressed the importance of the thermal hydraulics and safety.

About 15 key note addresses were delivered by the experts working in the area of thermal hydraulics and safety from different parts of the globe. Scientific staff, students, researchers working in this field benefited immensely during this workshop.

The workshop covered following themes:

- Challenges in Advanced Reactors.
- Regulatory Requirements / Guidelines for Advanced Nuclear Power Plants
- Thermal Hydraulics-Experimental and Numerical
- Severe Accident Management Guidelines
- Emergency Preparedness
- Strategies for Reactor Safety Enhancement
- Review of Major Accidents - Safety Insights Gained - Consequences and Combination of External Events.
- New Age Computer Codes and Application of PSA In Reactor Safety
- Advances in Passive Safety for Advanced Reactor

The workshop concluded with a panel discussion moderated by Dr. Prabhat Kumar, Project Director, BHAVINI. Prof. S. T. Revankar, Purdue University, USA, Shri S. G. Markandeya, BARC, Dr. Jong Ho Choi, IAEA and Shri K. K. Rajan, IGCAR were the other panelists. The discussion focused on addressing several important points mainly on passive system vs. active system, innovation of design for safety, lessons learnt from Fukushima accident and preparedness for future, medium for ultimate heat sink-air or water, margins for design basis / external events etc.

Participants during a technical session

"Multi-Objective Optimisation of Maintenance of Ship Borne Machinery and An Approach to Its Analysis Using Stochastic Petrinets"

Anil Rana, Interdisciplinary Programme in Reliability Engineering, Department of Electrical Engineering, Indian Institute of Technology Bombay, Mumbai - 400076

'Maintenance' as a function has today attained a very vital status in any Industrial set up including the defence services. The realization that the maintenance department is one of the largest beneficiaries of the annual budget has compelled the policy makers to institute methods to spruce up the manner in which it decides and executes the maintenance actions. These new methods should have brought about a shift in the basis on which the maintenance actions were being performed; from a mere rule of thumb or OEM's (Original Equipment Manufacturer) recommendations to scientifically based methods. Unfortunately, despite serious efforts by many theorists to research the field for rational maintenance decisions based on optimization models and their resultant recommendations, there still remains a wide gap between what is advocated and what is being practiced on ground. One of the main reasons for this gap is that there are an overwhelming variety of issues that need attention and there are no straight jacket solutions for every type of problem faced by the maintainers on field.

One of the ways to close this gap is to provide simplistic tools in the hands of the maintenance managers so that they can model the problem they face in accordance with its specific peculiarities. The research work presents a method to model the failure and wear/deterioration processes through a graphical modeling tool called stochastic petrinets. It demonstrates a method to model the non-exponential failure processes frequently encountered in practice, prepare the kernel and local kernel solutions along with a reachability graph and demonstrate its use by comparing the results with those achieved analytically.

On the other front the research work puts forward models and methods to address specific issues of maintenance. For a large setup, such as, ship borne machinery, it is proposed that the problem of taking optimal maintenance decisions need to be viewed systemically. The research work proposes optimization in maintenance at every hierarchical level of ship machinery. It presents a method to combine the knowledge of wear and deterioration amongst the various components of a large plant in order to use it for minimizing the maintenance interventions. Survey of literature has presented that the gamma non-stationary process is one of the best suited to model wear and deterioration. The author has shown a method to combine this information and create a convolution of the wear pdfs and use it within the constraints of individual wear limits to minimize the maintenance interventions of the plant. The time for maintenance intervention can then be based on the expected time for the plant to reach the combined wear threshold. If the probability of a specific component reaching its wear limit and the probability of the whole plant not reaching its combined wear threshold exceeds an acceptable value, another lower value of combined wear threshold can be chosen that satisfies the above condition.

The work further brings out decision making models to address issues such as making a decision between undertaking a time based or a condition based preventive maintenance on an equipment with choices based on wear thresholds, time for monitoring interval and probability of detection. Similarly a method has been presented to help the maintenance manager make an informed decision before opting to replace an entire equipment or only its individual failed component. In the end a multi-variable, multi-objective optimization problem is addressed based on an elitist GA (Genetic Algorithm) based program. The algorithm is used to prepare an optimal maintenance plan for a variety of ship borne machinery. It is shown by using an example that time based maintenance actions can be planned at two different levels. The first level comprises of a shorter maintenance period (MP) for a few selected equipment of the ship and the second level comprises of a maintenance plan for the entire (majority of) ship machinery called "refit". The number of MPs required, the number and type of equipment and the schedule of the MP and the refit depend on the objective values such as average reliability and cost rate of maintenance.

Another multi-objective optimization problem addressed through use of the GA program is that which is often faced by the maintainers of warships, wherein the time based planned maintenance is shelved for an immediate operational sortie of a ship. A short maintenance period may be granted to the maintainers in which he has to prepare the ship for maximum availability for the forthcoming operational sortie. The overwhelming number of components and the limited time available to the maintainer makes it difficult for him to choose the components for replacement in a cost effective manner. A sample problem has been solved based on an elitist GA program. A petrinet approach to address the above problem of analyzing the cost based on a similar problem has also been discussed.

Society for Reliability & Safety (SRESA)

(REG. NO. :3141/2010/G.B.B.S.D.)
ROOM NO. 68, LIFE CYCLE RELIABILITY ENGG. LAB, DHRUVA COMPLEX, BARC,
TROMBAY MUMBAI 400 085 (INDIA)
Web Site: www.sresa.org.in (PHONE ; +91-22-25596206)

Membership Application Form

Membership No. ______

(To be allotted by SRESA office)

1.	Name of the Applicant	
2.	Affiliation	
3.	Position held	
4.	Qualification	
5.	Field of Specialization (Attach separate sheet for more information)	
6.	Address:	
	Office:	Residence:
7.	Telephone No. (With STD Code) / Mobile No.	
	Office:	Residence:
8.	e-mail	
9.	Date of Birth(D/M/Y)	
10.	Type of membership applied for (Tick applicable category)	Annual Membership (Fee Rs.500/-) ☐ Life Member (Fee Rs.2000/-) ☐ Associate Member (Fee Rs.200/-) ☐ Corporate member (Fee Rs.50,000/-) ☐ Affiliate Member (Fee Rs.10,000/-) ☐ Emeritus Member & Patron* (Fee Nil) ☐ (Entry Fee Rs.200/- in addition to above membership Fee)

11.	Payment Mode		
	Cheque: ☐ Cheque No. : ……………. Date:……………………… Amount:…………………… Name of the Bank : ………. …………………………… ……………………………	Demand Draft: ☐ D D No: ……………. Date:………………….. Amount:…………….. Issuing Bank :………. ……………………… ………………………	Direct Deposit/Net Banking: ☐ Date:………………… Amount:……………… Transaction Details:…………… ………………………
12.	Signature:		

*(Kindly send soft copy of your Passport Size Photo to e-mail ID: **pkram@barc.gov.in)***

*Society Account Details: Money to be transferred in favour of 'Society for Reliability and Safety' SBI, BARC, Mumbai-400085 (India) Swift Code **: SBININBB508, Account Number 31110442604***

** Decided & recommended by Executive Committee*

Book-Post

If undelivered please return to
Society for Reliability & Safety
RN 68, Life Cycle Reliability Engg. Lab,
Dhruva Complex, BARC,
Mumbai - 400 085 (India)