THE INTERNATIONAL JOURNAL OF SCIENCE & TECHNOLEDGE

Analysis of the Management Strategies for the Ageing Process of a Nigeria Research Reactor

Uyigue, L.
Senior Lecturer, Department of Chemical Engineering, University of Port Harcourt, Nigeria
Edward, E. N.
Senior Scientific Officer, Centre for Nuclear, Energy Studies, University of Port Harcourt, Nigeria

Abstract:
This study focuses on the management strategies for the anticipated ageing process of a Nigerian research reactor (NIRR-1) which was acquired by the Federal Government in 2004 for the purposes of isotopes production and training. It was conducted using a semi-empirical method in which a questionnaire was used as the research instrument. The reliability index of the instrument was 75.4 %. Ageing indicators, causative factors and its detection mechanisms for NIRR-1 facilities were identified in the questionnaire and tested by subjecting them to respondent's opinions. From the results obtained, change in appearance (or colour), shape and size of facility, loss of weight of facility, equipment failure and leakage of radiation were accepted as ageing indicators for NIRR-1 based on a response mean > 3.0. Also, time, obsolescence, low integrity design, fire accident and severe service conditions were accepted as causative factors of NIRR-1 ageing, while heat oxidation, surface corrosion, erosion and microbial growth on NIRR-1 facility were accepted as detection mechanisms for ageing. One of the outcomes of this study is the draft algorithmic guideline for NIRR-1 ageing management.

Keywords: *Research reactor, ageing management, questionnaire, safety of operation, mean score, ranking order*

1. Introduction

Research Reactors are small nuclear reactors that are used for the production of radionuclide's (or radioisotopes) through method of irradiation. This radionuclide's serve useful purposes in medical diagnosis/therapy, material measurement and testing, biological characterization; oil logging services, agriculture/food preservation, forensics, imagery, radiography etc. Other applications of research reactor include Neutron activation analysis (NAA), scientific research, training purposes for technical and scientific personnel (IAEA, 1992). There are over 550 research reactors that have been constructed worldwide. About 300 are currently in operation. 13 of them are in Africa and 1 in Nigeria. Basic models of research reactors include Pool types, TRIGA, Heavy water (or graphite) types, Argonaut, Slowpoke etc. (IAEA, 2011).

The basic systems, structures and components (SSCs) of a research reactor include reactor core assembly, cooling systems, shielding structures, rabbit transfer system, gas purge system, ventilation system, reactor water monitoring system, instrumentation and control systems, and experimental facilities (IAEA, 1995). These SSCs can be exposed to severe service and operational occurrence conditions such as excess temperature, pressure, irradiation, stress, corrosion, fire and electric upsurge. Environmental and natural disaster conditions can expose reactors to humidity, storms (rain and wind), excess sunshine, flooding, earthquake, tsunami and volcano (IAEA, 2008; Buck and Villa, 2004). These conditions may lead to change in the properties of reactors SSC. This can affect the ageing process and safety functions of the reactor.

Age has also become a critical parameter for classifying research reactors: those whose first criticality is < 40 years and those ≥ 40 years (IAEA, 2011). Ageing is defined as the general process wherein the characteristics of the reactor SSC gradually changes with time or use (IAEA, 2010). This ageing process eventually leads to the degradation and deterioration of the reactor materials and its service conditions. The effects of such degradation on a research reactor facility may include defects in reactor's fuel elements assembly, change in chemical composition, fuel-cladding interaction and fuel depletion. Others are radiation leakages and contamination, loss of functionality and accuracy, and general loss of ability to function within accepted conditions of regulations which can compromise safety standards and facility utilization (Yusuf et al, 2011). These effects can create precarious conditions unless preventive and corrective measures are taken.

To make such preventive and corrective measures feasible, a good ageing management programme must be put in place. Ageing management is defined as an engineering operation that uses maintenance strategies and actions to control within acceptable limits the ageing degradation of research reactors Structures, Systems and Components (SSC). Management strategies of the ageing problems of research reactors include activities such as inspection, monitoring, testing, measurements, repairs, refurbishment and replacement of affected reactor's SSCs (IAEA, 2001 and 2005).

But for an enhanced management strategy for ageing, there may be need to regularly predict the structural behaviors of research reactor SSCs such as reactor vessel and core support structures which may often be affected by irradiation, in which many of the parts are difficult to replace (Schaaf et al, 2012). Also, data generated from appropriate maintenance and surveillance programmes with additional regulatory activity can help manage ageing problems and prevent unannounced shutdowns (Barnea *et al,* 2011). Post-service examination and testing of older research reactors from which data generated can be used as analysis tool for effectively managing the ageing problems of service reactors is also a welcome development.

This study is aimed at complimenting the existing ageing management programmes for the Nigeria Research Reactor (NIRR-1), while focusing on the use of semi-empirical method to identify the basic indicators, causative factors and detection mechanisms that may be associated with the NIRR-1 ageing process. Research questions relating to this study were formulated and tested using a questionnaire and the results obtained were used to develop guidelines for managing the ageing problems.

1.1. Overview of Nigeria Research Reactor (NIRR-1)

NIRR-1 is the code name for Nigeria first research reactor. It was installed and commissioned in 2004. Its model is a pool type also called pressurized water reactor (PWR) type. It has a small power capacity of 30 kW and it is equipped with radiation detectors: gamma-ray spectrometer and isotope ratio mass spectrometer. Additional infrastructures attached to the reactor are low level waste (LLW) storage facility, 14 MeV sealed (or guide) tube and isotopic neutron sources. Mechanical and nuclear electronics workshops are part of its supporting facilities. It is located at the Center for Energy Research and Training (CERT), Ahmadu Bello University, Zaria (Jonah and Balogun, 2005; CERT, 2005).

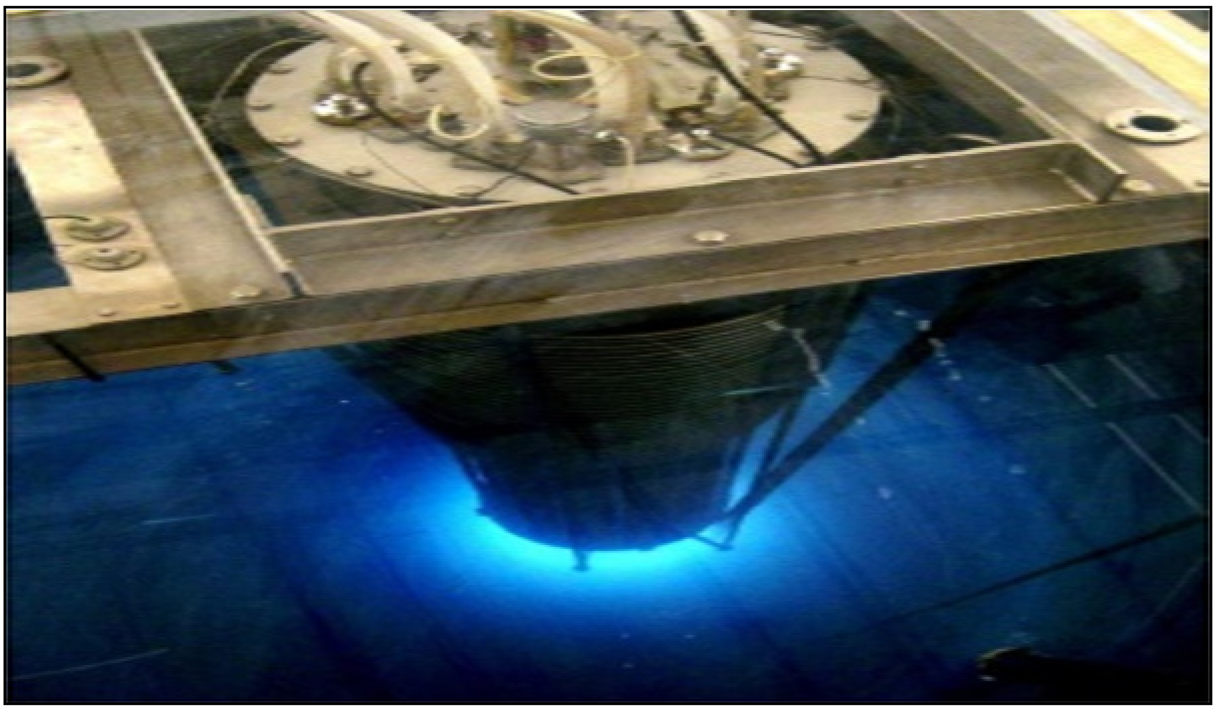

Figure 1: A side photographic view of NIRR-1 (CERT, 2005).

2. Methodology

A structured questionnaire was used as instrument for the study. In it, questions drawn from screening parameters for ageing and its detection mechanisms for the NIRR-1 and its relationship to the safety of the reactor were tested with respondent's opinions. The categories of respondents for this study were scientists, engineers and technicians not below the rank of civil service level 10 or its equivalents. An estimated total population of respondents for this study was two thousand, five hundred (2,500). The sampling method adopted was the stratified random sampling based on simple balloting. Consequently, one hundred (100) respondents drawn from fifteen (15) out of the twenty (20) identified nuclear related establishments in Nigeria constituted the samples of this study.

2.1. Sampling Instrument

The title of the questionnaire was **"Ageing management strategies for a Nigeria Research Reactor-1".** It was designed into three (3) sections: A, B and C. Section A contains the biometric information of the respondent, section B contains the basic instructions for answering the questionnaires while section C had the questionnaire variables which were mainly questions centered on screening parameters for ageing process, ageing detectors and ageing mechanisms. The questionnaire was structured to have different research questions relating to NIRR-1 ageing process. Under each research question contains different questionnaire items which are direct questions relating to the subject matter.

The weight of the responses was based on modified five points scale of Strongly Agree (SA), Agree (A), No Opinion (NO), Disagree (D) and Strongly Disagree (SD), respectively given as: SA=5, A=4, NO=3, D=2 and SD=1. The weighted mean was calculated as,

$$Weighted \quad Mean = \frac{5+4+3+2+1}{5} = \frac{15}{5} = 3.0 \qquad (1)$$

2.2. Reliability Index

The reliability index was used to determine the suitability of the questionnaire for this study. Method of test-retest was used to determine the actual value. It was carried out by administering the questionnaire to 20 respondents who were not part of the actual samples for the study within the interval of two weeks on the basis of 10 respondents at a time. The two (2) sets of results were co-related using *Pearson's Product Coefficient* (eq. 2)to estimate the index (ρ_{xy}). The value obtained was 0.75, which is high enough and reliable when compared with other studies.

$$\rho_{xy} = \frac{N(\sum xy) - (\sum x)(\sum y)}{\sqrt{\left[(N(\sum x^2) - (\sum x)^2)(N(\sum y^2) - (\sum y)^2)\right]}} \qquad (2)$$

Where, ρ_{xy} = reliability index, %; N = number of respondents; x, y = scores from respondents; $\sum$ = summation

2.3. Data Analysis

The respondents were contacted through written letters attached to the questionnaire, and were handed to them personally, by post and by email. The responses were collected via the same route. The responses obtained were collated in tables and analyzed using basic statistics. This work made use of mean scores (MS) and ranking order as tools for evaluating the responses obtained from the questionnaire. The MS parameter is defined as follows,

$$MS = \frac{\sum_i (F_i \ x \ S_i)}{N} \qquad (3)$$

Where, F = frequency of response key to a questionnaire item, S = score assigned to a response key for a given questionnaire item, N = total number of responses to a given questionnaire item and i = number of response key.

Also, the ranking order is the positioning of all tested questionnaire items (based on MS value) within a research question under study. A criterion mean of 3.0 was adopted. It implies that a response mean score greater than or equal to 3.0 for a questionnaire item is accepted, while a response mean score less than 3.0 is rejected.

3. Discussion of Results

The results obtained were derived mainly from the responses of respondents and will be discussed as follows: Reliability index for research instrument, Analysis of responses to questionnaire items and algorithmic guideline for screening and ageing management of NIRR-1.

3.1. Reliability Index of Research Instrument

The Pearson's Product Coefficient was used to calculate the reliability index (Table 1). An index of 75.4 % was obtained. This was an indication that the administered questionnaire captures to a large extent the fundamental thrust of the study. The reason was because the responses X and Y obtained from the two separate trials showed similar trend.

Respondent	X	Y	X^2	Y^2	XY
1	133	135	17689	18225	17955
2	136	142	18496	20164	19312
3	140	145	19600	21025	20300
4	126	132	15876	17424	16632
5	128	118	16384	13924	15104
6	138	120	19044	14400	16560
7	100	106	10000	11236	10600
8	141	133	19881	17689	18753
9	136	133	18496	17689	18088
10	118	124	13924	15376	14632
SUM = $\sum$	1296	1288	169390	167152	167936

Table 1: Reliability test calculation for the research instrument
NB: X and Y, are the total weighted responses of respondent for the two trials and reliability index, ρ_{xy} = 0.75 (or 75 %)

3.2. Screening Parameters for NIRR-1 Ageing Process

Four research questions were presented under this study, from which a total of 22 questionnaire items were tested. Research question 1: Justification of the effect of NIRR-1 utilization level by its community on ageing parameters; research question 2: effects of SSC characteristics of NIRR-1 on its ageing parameters; research question 3: implications of ageing on the design and safe operation of NIRR-1 and research question 4: impact of day to day operation of NIRR-1 on its ageing parameters.

The results obtained from research question 1, as shown in Table 2 indicates that the questionnaire items parameters such as time-after-first-criticality, level of utilization, obsolescence and funding of NIRR-1 were all accepted as factors that can affect the ageing process of NIRR-1.

S/N	Questionnaire item	SA	A	NO	D	SD	Total	Mean	Rank	Remark
i.	Time-after-first-criticality and obsolescence are important ageing factors.	500	-	-	-	-	500	5.0	1st	Accepted
ii.	The lack of patronage for the NIRR-1 is as a result of low nuclear education in Nigeria.	125	300	-	-	-	425	4.25	2nd	Accepted
iii.	Funding NIRR-1 by Government alone can cause increased ageing rate.	50	160	-	100	-	310	3.1	3rd	Accepted
iv.	Under or over utilization of NIRR-1 can induce its ageing.	-	320	60	-	-	380	3.8	4th	Accepted

Table 2: Analysis of questionnaire items on the justification of the effect of NIRR-1 utilization level by its community on its ageing parameters

For research question 2, the results obtained (Table 3) showed that indicators such as properties of materials used for fabricating the NIRR-1 SSC's (such as sensitivity to corrosion, heat etc.) were accepted as factors that can affect its ageing process to a large extent. Also, color change, shrinkage and loss of weight were accepted as identifiable ageing indicators for NIRR-1. However, low thermal expansion materials were not accepted as age inducing properties.

S/N	Questionnaire item	SA	A	NO	D	SD	Total	Mean	Rank	Remark
i.	There are material codes for fabricating different SSC of NIRR-1.	50	320	30	-	-	400	4.0	4th	Accepted
ii.	SSC materials with low thermal expansion cause ageing of NIRR-1.	35	52	-	160	-	247	2.47	5th	Rejected
iii.	SSC fabricated with corrosion sensitive materials can cause quick ageing of NIRR-1.	335	132	-	-	-	467	4.67	1st	Accepted
iv.	Ageing is a causative factor of material's failure.	300	160	-	-	-	460	4.6	2nd	Accepted
v.	Identified colour change, weight loss and shrinkage of NIRR-1 SSC are parameters of its ageing process.	25	380	-	-	-	405	4.05	3rd	Accepted

Table 3: Analysis of questionnaire items on the effects of systems, structures and components (SSC) characteristics on ageing parameters of NIRR-1

As shown in Table 4, ageing process is accepted as factor that can seriously affect the integrity of NIRR-1 SSC designs, and that low integrity designs for NIRR-1 SSC can result in defects in fuel assembly and reactor core which can in turn have serious safety implications. However, high or low temperature profile of the reactor core was rejected as a factor that can accelerate ageing in NIRR-1. However, temperature can be a factor of ageing only if the cooling system is ineffective.

S/N	Questionnaire item	SA	A	NO	D	SD	Total	Mean	Rank	Remark
i.	Integrity of NIRR-1 design can be affected by ageing.	325	140	-	-	-	465	4.65	2nd	Accepted
ii.	Low integrity of a design can have serious safety implications.	350	120	-	-	-	470	4.7	1st	Accepted
iii.	Regular over (or under) temperature in the reactor core accelerates ageing of NIRR-1.	-	100	-	150	-	250	2.5	5th	Rejected
iv.	Cladding defect in the reactor fuel assemblies may have safety implications on NIRR-1 operation.	-	400	-	-	-	400	4.0	4th	Accepted
v.	Ageing of SSC of the reactor core of NIRR-1 can cause radiation leakages.	200	240	-	-	-	440	4.4	3rd	Accepted

Table 4: Analysis of questionnaire items on the implications of ageing on the design and safe operation of NIRR-1

Wearing, tearing and vibration of mechanical parts were accepted as factors that can accelerates the ageing of NIRR-1 SSC as shown in the Table 5 (analysis of research question 4). Also, poor cooling, improper regulation, operator's incompetence, unfavorable environmental conditions, exposures to radiation and fire were accepted as key factors that can accelerate the ageing process of NIRR-1. However, electric current surge and flow lines interruption were rejected as factor that can affect reactor ageing.

S/N	Questionnaire item	SA	A	NO	D	SD	Total	Mean	Rank	Remark
i.	Wearing, tearing and vibration of mechanical parts of reactor's SSC can accelerate ageing of NIRR-1.	200	160	60	-	-	420	4.2	4th	Accepted
ii.	Poor management of reactor cooling systems affects NIRR-1 ageing process.	225	180	-	20	-	425	4.25	3rd	Accepted
iii.	Blockage (or interruption) of flow lines in an NIRR-1 operation can cause ageing.	-	20	30	120	25	195	1.95	8th	Rejected
iv.	Exposure of NIRR-1 SSC features to unfavourable environmental factors: humidity, temperature, chemical, flood etc. can accelerate.	225	220	-	-	-	445	4.45	2nd	Accepted
v.	Electric current surge on the NIRR-1 power systems can cause the ageing of the SSC features.	-	28	30	166	-	224	2.24	7th	Rejected
vi.	Exposure of SSC of NIRR-1 to radiation accelerates its ageing process.	-	160	60	80	-	300	3.00	6th	Accepted
vii.	Fire accident in a research reactor can be linked more onto safety than ageing problems.	400	-	60	-	-	460	4.6	1st	Accepted
viii.	Poor regulation and operator's incompetence can lead to accelerated ageing of SSC of NIRR-1.	-	400	-	-	-	400	4.00	5th	Accepted

Table 5: Analysis of questionnaire items on the impact of day to day operation of NIRR-1 on its ageing parameters

- Ageing detection mechanism for the NIRR-1

Three research questions were presented for this study from which a total of 9 questionnaire items were tested: Research question 5: physical-mechanical mechanisms of NIRR-1 ageing process; research question 6: chemical mechanism of NIRR-1 ageing process and research question 7: biological mechanism of NIRR-1 ageing process. The analysis of research question 5 (Table 6) accepted as key signs of the ageing of reactor facility, the detected changes in the appearance, shape and size of the NIRR-1 SSC which may be caused by thermal expansion and contraction, or impacts by falling objects or natural disaster. Also, excessive and sustainable heat accumulation in the reactor system without proper ventilation or evacuation was accepted to cause acceleration of ageing process.

S/N	Questionnaire item	SA	A	NO	D	SD	Total	Mean	Rank	Remark
i.	The change in the shape or appearance of SSC features of a NIRR-1 is a sign of ageing.	-	180	135	20	-	335	3.35	3rd	Accepted
ii.	Impacts on NIRR-1 SSC features caused by falling objects can cause its ageing.	-	140	90	70	-	300	3.00	4th	Accepted
iii.	Impacts occasioned by natural disaster on NIRR-1 SSC features can cause ageing.	40	288	30	20	-	378	3.78	2nd	Accepted
iv.	Excessive heat accumulation in the NIRR-1 compartment, without good ventilation system, causes accelerated ageing.	185	148	78	-	-	411	4.11	1st	Accepted

Table 6: Analysis of questionnaire items on the physical-mechanical mechanism of NIRR-1 ageing process

From the analysis of research questions 6 and 7 (shown in Tables 7 and 8), it was accepted that exposures of NIRR-1 SSC materials to acids; solvents, oxidative gases, irradiation and algae growth are factors which can accelerate the ageing process. This is because ageing detection mechanisms like corrosion, erosion, oxidation and calcium migration are usually associated with such exposures.

S/N	Questionnaire item	SA	A	NO	D	SD	Total	Mean	Rank	Remark
i.	Corrosion or erosion of SSC features of NIRR-1 can cause its ageing.	340	128	-	-	-	468	4.68	1st	Accepted
ii.	Exposure of NIRR-1 SSC features to acids, solvents and oxidative gases can cause its accelerated ageing.	340	80	-	24	-	444	4.44	2nd	Accepted
iii.	Change in the chemical form of materials used for building SSC of NIRR-1 due to excessive neutron irradiation or heat oxidation can cause ageing.	-	356	-	22	-	378	3.78	3rd	Accepted

Table 7: Analysis of questionnaire items on the chemical mechanism of NIRR-1 ageing process

S/N	Questionnaire item	SA	A	NO	D	SD	Total	Mean	Rank	Remark
i.	Reactor's concrete shield contaminated with algae growths can cause accelerated ageing.	85	312	-	-	5	402	4.02	1st	Accepted
ii.	Calcium migration of the NIRR-1 concrete shielding can cause ageing process.	-	380	-	-	5	385	3.85	2nd	Accepted

Table 8: Analysis of questionnaire items on the biological mechanism of NIRR-1 ageing process

- Algorithmic guideline for managing NIRR-1 ageing facility

It is a simple sequence of instructions or guides that would help manage the anticipated ageing process of a NIRR-1 facility (see Figure 2). It involves general evaluation of NIRR-1 structure, system and component in relation to safe operation, and followed by screening of the facility physical features for ageing problems and subjects the affected facility to ageing management.

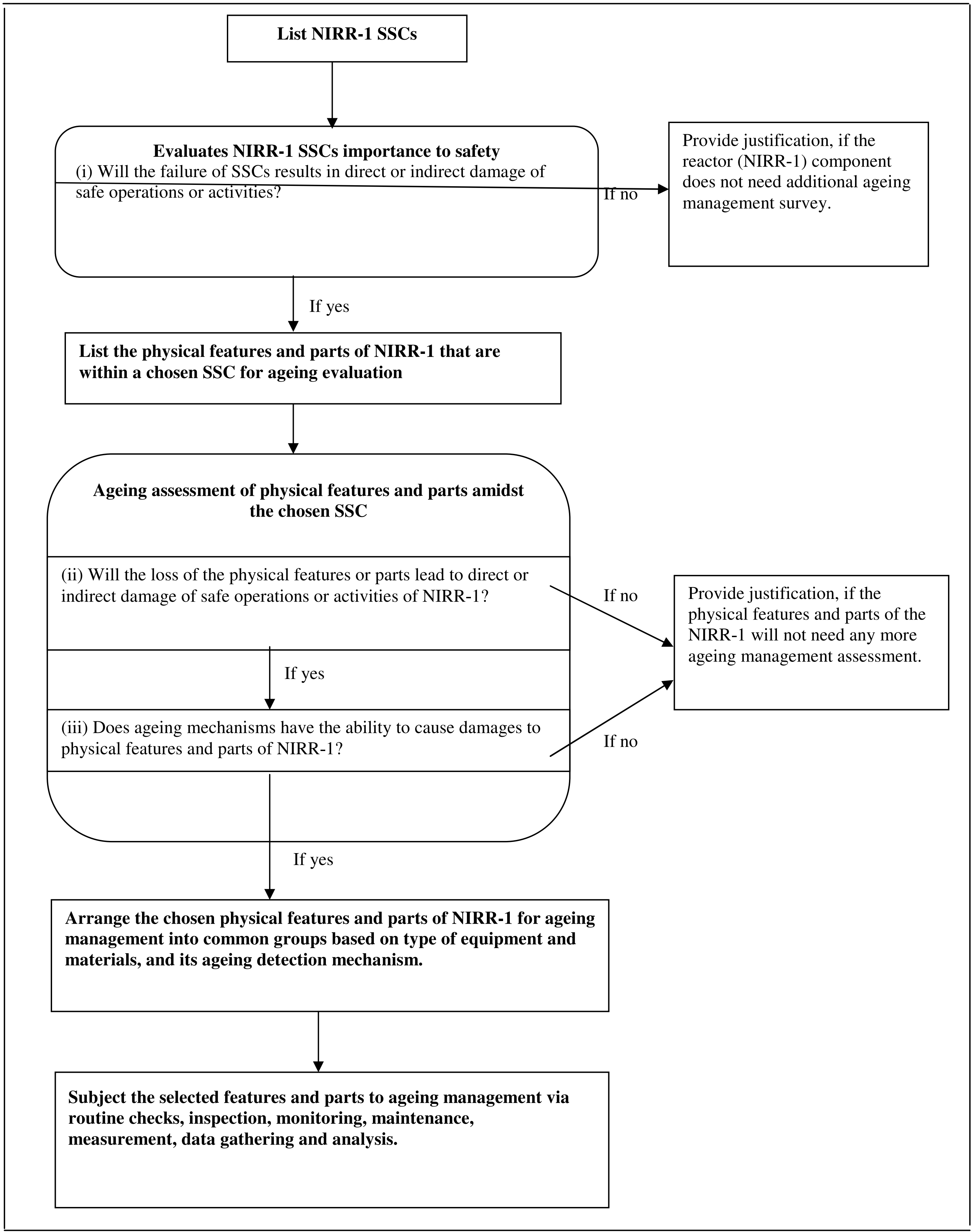

Figure 2: Algorithmic guideline for screening and ageing management of NIRR-1 SSC

4. Conclusions

The applied questionnaire for the NIRR-1 ageing management strategy analysis was valid and reliable (reliability index = 75.4 %). The results obtained from the study will form platforms for actual experimentation and measurements. Prominent indicators for NIRR-1 SSC ageing process are identified as color change, shape or size change, loss of weight, equipment failures and radiation leakage. Also, outstanding causative factors (amongst others) identified for the anticipated ageing process of the research reactor are time, obsolescence, low integrity of design, fire accident, heat accumulation, service conditions and environmental exposures, while the mechanisms for detecting the ageing process are identified as heat oxidation, surface corrosion, erosion, calcium migration and microbial growth. However, some identified technical factors such as flow line obstruction, fluctuating temperature of an operating unit and electric current surge are not likely to accelerate the reactor's ageing process. Therefore, for effective ageing management of NIRR-1 facility, a drafted algorithmic guideline was suggested.

5. Notation

- CERT: Center for energy research and training
- NIRR-1: Nigeria research reactor 1
- SSC: Systems, structures and components
- IAEA: International atomic energy agency
- TRIGA: Training, research, irradiation and general atomics
- SA, A, NO, D, SD: Strongly agree, agree, no opinion, disagree and strongly Disagree
- MS: Mean score

6. References

i. IAEA, 'Manual on reliability data collection for research reactor', TECDOC-636, IAEA, Vienna, 1992.
ii. IAEA, 'Research reactor application for materials under high neutron flux', TECDOC-1659, Vienna, 2011.
iii. IAEA, 'Management of research reactor ageing', IAEA-TECDOC-792, Vienna, 1995.
iv. IAEA, 'Operational limits and conditions and operating procedures for research reactors', Safety standards series No. NS-G-4.4, Vienna, 2008.
v. IAEA, 'Safety glossary: terminology used in nuclear safety and radiation protection', Vienna, 2007.
vi. IAEA, 'Ageing management for research reactors', Safety standards series No. SSG-10, Vienna, 2010.
vii. Yusuf, I., Mansir, I.B., Dewu, B.B.M., 'Maintenance as a tool for the enhancement of safety in the operation of Nigeria research reactor', International conference on research reactors: safe management and effective utilization, 2011.
viii. IAEA, 'Application of non-destructive testing and in-service inspection to research reactors', TECDOC-1263, Vienna, 2001.
ix. IAEA, 'Maintenance, periodic testing and inspection of research reactors', IAEA Safety standards Series No. NS-G-4.2, Vienna, 2005.
x. Barnea, Y., Zeman, A., Bradley Jr. E., and Adelfang, P., 'IAEA database on assessment, monitoring and surveillance of research reactors core structural materials ageing', Proceedings of the conference on structural mechanics in reactor Technology, No. 21, New Delhi, India, 2011.
xi. Jonah, S.A. and Balogun, G.I., 'Current status of the NIRR-1 and feasibility for conversion to LEU', Paper presented at 27th international meeting on reduced enrichment for research and test reactors, Boston, USA, 2005.
xii. Schaaf, B.V.D., Barnea, Y., Zeman, A., Borio di Tigliole, A., Adelfang, P., Bradley, E. and Shokr, A., (2012). 'Material properties database for irradiated core structural components for continued safe operation and lifetime extension of ageing research reactors', Fifth international symposium on material testing reactors in Columbia, Missouri, USA, 2012.
xiii. CERT, 'Safety analysis report of NIRR-1', Technical report of CERT/NIRR-1/FSAR-01, Zaria, 2005.
xiv. Bock, H. and Villa, M., 'Examples of in-service inspections and a typical maintenance schedule for low power research reactors', Prepared for IAEA, under contractual service agreement Pers/JCH/nbb/ior/NSNI/Rev.1, 2004.