Application of In- Service-Inspection in Nuclear Reactors

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ABSTRACT

The in-service inspection (ISI) is essential to prove the safe operation of the reactor, and to take an accurate decision about the degree of aging and availability of the components and systems important to safety in the nuclear power plant. The ISI program comprises : the technical examination of the reactor vessel, inspection of the main cooling system (coolant pumps, steam generators, coolant pipes. valves) and the pressurizer as also, other special components in the pressurized water reactor nuclear power plant. Special techniques and inspection methodologies for the Egyptian research reactor (ET-RR-1) are presented. The ISI of the reactor tank of (ETRR-1) revealed that the metal surface is mainly exposed to pitting, and the number and size of pits do not prevent the operation of the reactor under normal water and chemical conditions.

This work gives information about the degree of aging of the (ETRR-1), which can be operated safely with the same capacity.

Keywords: In-service-Inspection, Visual Examination, Volumetric Examination, Surface Examination.

INTRODUCTION

Components and systems of a nuclear power plant might be exposed to influences such as stress, temperature, irradiation, hydrogen absorption, corrosive attack , vibration and fretting, all of which depend upon time and operating history. These influences(single or combined) may result in changes of material properties such as aging, embrittlement, fatigue and formation and/or growth of flaws [1,2].

In view of this, it is therefore necessary to plan and implement ISI to examine the systems and components of the plant for possible deterioration so as to judge whether they are acceptable for continued safe operation of the plant or whether remedial methods are necessary.

A pre-service inspection should be performed before the commencement of plant operation to provide data on initial conditions supplementing manufacturing and construction data as a basis for comparison with subsequent ISI .When a component is repaired or replaced, a pre-service examination should be performed on that component.

In-service-inspection requires appropriate provisions in the design of the plant for accessibility of components to be examined and for keeping radiation exposures of examination personnel as low as reasonably achievable.

The acceptance standards for examinations and tests and corrective actions such as repair or replacement of components ascertained to be unsatisfactory should be chosen accordingly. Safety classes assigned in the design of the plant may also be taken into consideration in the ranking of the importance of systems and components for safety and consequently for their in-service-inspection classification.

In this paper we will study the new techniques concerning the ISI using different methods of examination such as visual, volumetric and surface examinations. The results of the case study of the Egyptian Research Reactor(ETTR-1)have been analyzed, and recommendations based on that inspection techniques were elaborated.

PLANNING, PREPARATORY WORK FOR AND PERFORMANCE OF AN IN- SERVICE INSPECTION

In-service inspection program

- Preparation of an overall in-service inspection plan in concurrence with code [3]: e.g. US examination of reactor pressure vessel every Four years
- Eddy- current examination of steam generators: Two steam generators per year
- Preparation of individual in-service inspection program
- Establish scope of test
- Establish testing technique
- Submission of examination procedure specification

Preparatory work relating to in-service inspection

- Preparation of schedule and correlation with the overall plan for activities during plant shut down
- Provision of qualified staff:
  - · inspectors (certificate)
  - · operators (computers, manipulators)
  - · assembly personnel (training)
- Compliance with formal requirements (approval for shift work, plant safeguards, radiological protection of personnel)

Performance of in - service inspection

- Transportation of equipment (transport of irradiated material)
- Plant formalities (radiological protection , accident prevention , etc.)
- Bringing into position, setting up and checking of equipment
- Adjustment and calibration at the same time
- Preparation of location for performance of inspection (e.g. UT examination of PWR pressure vessel : remove closure head, unload core, extract internals)
- Start of in-service inspection, supervised by competent inspection agency
- Regular adjustments
- On-line representation of results
- Comparison with results of previous in - service inspections
- Acceptance of performance and results by competent inspection agency.
- Preparation of documentation
- Disassembly (and decontamination, if necessary) of examination equipment
- Check and transportation from plant,
- parallel organizational measures:
  - · check for compliance with and co-ordination of deadline
  - · monitoring of working time
  - · monitoring of radiation dose

DOCUMENTATION

Relevance of documentation

- Basis for comparison with results of subsequent in-service-inspections
- Basis for evaluation if examination technique is changed
- Evidence of integrity at time of inspection and basis for prognostic demonstration of integrity

Requirements made of documentation

- Compilation of all values affecting the information values of the test results
- Storage media suitable for long-term storage:(magnetic tapes, magnetic discs, recorder charts, computer printouts, etc.)

Example of documentation content

- In- service inspection program comprises
  - · in-service inspection sequence plan
  - · examination procedure specification
  - · equipment used
  - · logs for probes and calibration
- Test results including
  - · lists of results
  - · result logs
  - · result atlas
- Data compilation
  - · pictures of indications
  - · analog reactor charts
- Storage media
  - · magnetic tape library
  - · selection of magnetic tapes
- Performance
  - · records of performance
  - · deadline schedules
  - · records of radiation doses received
- Test report
- Summary

DATA EVALUATION

General remark

Situation

- The vast majority of data gathered applies to regions without flaw indications
- Most indications are spurious indications or minor indications
- Deciding between spurious indications, minor indications and major indications requires systematic evaluation

Strategy

- Search technique for rapid detection of indications with the possibility of classification
- Use of analyzing techniques for indication evaluation

Objective

- Detection of flaws
- Determination of category
- Establishment of position, orientation, size
- Comparison with previous test results
- Establishment of permissibility or initiation of further measures(further analysis, examination by fracture mechanics repair measures, etc.)

Procedure

- Identification of indications out of the measured data (e.g. by computerized indication detection)
- Identification of pseudo indications (geometrical echo etc.)
- Comparison with evaluation threshold (if necessary)
- Comparison with indication from previous test (if necessary)
- Further analysis of the non-reduced raw data (if necessary)
- Use of analyzing methods (if necessary)

Human Aspects

- Computer assisted systems provide the required information
- The evaluation as to the nature, position and size of the indication is provided by the inspector
- Training experience

OVERVIEW OF IN - SERVICE - INSPECTION (ISI)TECHNIQUES

- All ISI Techniques are also applicable to pre-service inspection and shop quality control
- All ISI Techniques rely on nondestructive testing (NDT)[4].
- The Techniques can be divided into Three categories :
  - Visual Examination
  - Surface Examination
  - Volumetric Examination

Visual Examination

A visual examination is used to provide information on the general condition of the part component or surface to be examined, including such conditions as scratches, wear, cracks, corrosion or erosion on the surface; or evidence of leaking. Optical aids such as television cameras, binoculars and mirrors may be used.

Surface replication as a visual examination method may be considered acceptable, provided that the surface resolution is at least equivalent to that obtainable by the visual observation.

Visual examination that requires clean surface or decontamination for valid interpretation of results shall be preceded by appropriate cleaning processes. Visual examination techniques are applied to an indefinite range of materials in the forms of surfaces, layers, films, coatings; entire objects.

Surface Examination

A surface examination is undertaken to delineate or to verify the presence of surface or near-surface flaws or discontinuities. The surface inspection methods are:

- Visual / optical
- Magnetic particle
- Liquid (dye) penetrant
- Eddy current

Magnetic particle inspection

In this form of inspection a specimen is first magnetized and its surfaces then dusted with very fine particles of ferromagnetic material. The particles are attracted to the free poles in its surface caused by defects. The method is suitable only for ferromagnetic materials and is limited to the detection of defects at or very close to the surface. Very few restrictions apply regarding size and shape of a specimen and the method may be used on smooth surfaces which have been given an anti-corrosive protective coating, e.g. paint, cadmium plating, etc.

Liquid penetrants inspection

This method of inspection is most suitable for the detection of small surface opening defects. It relies upon the application of a liquid dye to the material and the ability of defects in its surface to absorb the dye by capillary action. The presence of a defect is rendered visible to the naked eye by removing excess liquid from the material and observing the subsequent seepage of dye from the defect. The method is suitable for all types of nonporous materials having smooth, clean; uncoated surfaces. It is not suitable for surfaces which have been sand-blasted, painted, plated, or contaminated by oil, grease, or oxide particles.

Penetrant materials may be applied to surfaces by brush, spray or total immersion. The method used being determined by the type, size, and number of specimens to be examined , and by the type of penetrant used.

Eddy-current testing

Eddy-current technique is used for the examination of metal objects to determine the presence of flaws, seams, joints, voids, etc., or for the sorting of dissimilar metals or the measurement of grain size, hardness, coating thickness, and many other properties and characteristics.

The technique is based upon the principles of electromagnetic induction and on the interaction which occurs between a coil energized with alternating current and the object being examined.

Volumetric Examination

A volumetric examination is undertaken for the purpose of indicating the presence, location and size of flaws or discontinuities anywhere within the material. The volumetric inspection methods are:

- Radiography
  - . X-Ray
  - . Gamma Ray
  - . Neutron
- Ultrasonics
- Eddy - current

X- and gamma- radiography

Inspection by x-or gamma- rays is carried out by irradiating one surface of the specimen with x-or gamma-radiation whilst a radiation-sensitive film is held in a light-tight cassette against the opposite surface. The radiation, in passing through the specimen, is differentially absorbed by discontinuities caused by flaws, voids, changes in thickness or material density, and a latent image of the variations, integrated throughout the sample thickness, is produced on the film in the same way as visible light is made to produce an image on a photographic film. After the film has been developed, variations within the specimen appear with shadow objects of differing half-tone, from which information may be obtained about the presence of flaws and misaligned, broken, or disconnected mechanisms. The record produced in this way is known as a radiograph.

Neutron radiography

Neutron radiography is a non-destructive testing (NDT) technique which can sometimes provide useful information, not revealed by any other method, about the internal structure or composition of a specimen. The technique is similar in principle to x- and gamma- radiography except that it uses a beam of neutrons, instead of x-or gamma radiation, to produce a projected shadow image.

The application of neutron radiography are :

- Distinguishing a cadmium-plated component from one which has been zinc -plated
- Location and examination of the glue in lapped metal joints.
- The detection of inclusions of hydrides in zirconium or titanium components
- The use of water or oil as a contrast agent to delineate the run of cooling passages in a hollow casting

  Inspecting ordnance products and explosive bolts for proper filling

Monitoring for corrosive products in light-alloy structures

- Radiographing highly radioactive components, e.g. nuclear reactor fuel elements and rigs.

Ultrasonic testing

'Ultrasonics' is a term used to describe an inspection or measurement technique which makes use of sound waves whose frequencies are higher than those detectable by the human ear. Typical ultrasonic frequencies used for NDT extend from about 100 kHz to 25 MHz. Ultrasonic techniques are widely used in applications ranging from flaw detection to thickness gauging and fluid-flow measurement.

Ultrasound is usually generated by a transducer (probe) constructed from a piezo - electric crystal such as quartz or lithium sulphate or a ceramic such as barium titanate or lead zirconate titanate (PZT). These materials possess the reciprocal properties of being able to convert electrical energy into mechanical energy and mechanical energy into electrical energy. Such transducers are therefore able to function as either transmitters or receivers of ultrasound.

Two main methods of using an ultrasonic transducer are used for NDT inspection:

- In the transmission method a transducer is functioning as a transmitter injects a continuous stream of ultrasonic energy into one surface of the specimen being examined whilst a second transducer, functioning as receiver accepts the energy reaching the opposite surface. By slowly scanning the surfaces of the specimen either by movement of the specimen itself or by simultaneous movement of both transducers and examining an oscillographic, or chart recording of the received ultrasonic energy , the presence of flaws in the specimen can be readily observed as a reduction in signal strength.
- In the pulse-echo, or acoustic radar, method, a transducer functioning as a transmitter injects a series of short duration pulses of ultrasonic energy into one surface of the specimen. At the end of each pulse, and until the arrival of the next, the same transducer assumes the role of a receiver and accepts ultrasonic energy which is reflected from suitably orientated internal flaws, and from the opposite surface of the specimen . By displaying the transmitted pulse and the return echoes on the time base of an oscilloscope, it is possible not only to detect the presence of flaws in the specimen but also to estimate their location, relative to the transmission surface, by measuring their distances on the time base from the transmitted pulse. The pulse-echo method is also valuable for determining the thickness of a specimen by measuring the time base distance of the echo obtained from the opposite surface.

SELECTION OF ISI TECHNIQUES

A list of typical components of boiling and pressurized water reactors (BWR & PWR) power plant and possible methods of examination are given in Table 1[1,3].

CASE STUDY ETRR-1 REACTOR

Inspection of Reactor Tank and Spent Fuel Storage

General

ETRR-1 Inshass Reactor is 2 MW, tank type research reactor with light water moderator, coolant and reflector. The reactor tank and spent fuel storage are made of aluminum alloy. Cooling circuit, pumps, heat exchangers and valves are manufactured from stainless steel. The initial condition of reactor components is unknown; pre-service inspection records are not available [5].

Objectives of the ISI Program

- Verification the condition of reactor components
- Evaluating the flaws and defects revealed on the acceptance standards
- Assessing the corrective actions such as repair or replacement of components for continued safe operation and for reactor power upgrading.

ISI Techniques

Visual examination

- TV system is designed for surface inspection under water [6,7]

Table 1 Components, parts, and methods of examination

Components and parts to be Examined	Method
Reactor Vessel	
Longitudinal and circumferential shell welds	Volumetric
Meridional and cirumferential head welds Vessel-to-flange and head-flange	Volumetric
circumferential welds	Volumetric
Primary nozzle-to-vessel welds and nozzle inside radiused section	Volumetric
Vessel penetrations, including control rod drive and instrumentation penetrations	Visual
Nozzle-to-safe end welds	Volumetric &surface
Nuts	Surface
Closure studs, in place	Volumetric
Closure studs, when removed	Volumetric &Surface
Ligaments between threaded stud holes	Volumetric
Closure washers, bushings	Visual
Pressure retaining bolting	Visual
Vessel supports	Surface or Volumetric
Vessel interior	Visual
Interior attachments and core support structures	Visual
Core support structures	Visual
Control rod drive housing	Surface or Volumetric
Exempted components	Visual
Pressurizer	
Longitudinal and circumferential welds	Volumetric
Nozzle-to-vessel welds and nozzle-to-vessel radiused section	Volumetric
Heater penetrations	Visual
Nozzle-to sate end welds	Volumetric &Surface
Pressure retaining bolts and studs, in place	Volumetric
Pressure retaining bolts and studs, when removed	Volumetric &Surface
pressure retaining bolting	Visual
Vessel Supports	Surface or Volumetric
Exempted components	Visual
Heat Exchangers and steam Generators	
Longitudinal and circumferential welds, including tube sheet-to head or shell welds on the primary side	Volumetric
Nozzle-to-head welds and nozzle inside radiused section on the primary side	Volumetric
Nozzle-to-safe end welds	Volumetric &Surface
Pressure retaining bolts and studs, in place	Volumetric
Pressure retaining bolts and studs, removed	Volumetric &Surface
Pressure retaining bolting	Visual
Vessel supports	Surface or Volumetric
Exempted components	Visual
Steam generator tubing	Volumetric
Piping Pressure Boundary	
Safe-end to piping welds and safe-end in branch piping welds	Volumetric &Surface
Pressure retaining bolts and studs, in place	Volumetric
Pressure retaining bolts and studs, when removed	Volumetric &Surface
Pressure retaining bolting	Visual
Circumferential and longitudinal piping welds in nominal pipe sizes 4 in. and greater	Volumetric &Surface
Circumferential and longitudinal piping welds in nominal pipe sizes less than 4 in.	Surface
Branch pipe connection welds	Surface
Socket welds	Surface
Support members	Surface or Volumetric
Support components	Visual
Exempted components	Visual
Pressure retaining bolting	Visual

Table 1 Components, parts, and methods of examination (*Continued*)

Pump Pressure Boundary	
Pressure retaining bolts and studs , in place	Volumetric
Pressure retaining bolts and studs, when removed	Volumetric &Surface
Pressure retaining bolting	Visual
Support members	Surface or Volumetric
Support components	Visual
Pump casting welds	Volumetric (Surface as required)
Pump casting	Visual
Exempted components	Visual
Valve Pressure Boundary	
Pressure retaining bolts and studs, in place	Volumetric
Pressure retaining bolts and studs, when removed	Volumetric &Surface
Pressure retaining bolting	Visual
Support members	Surface or Volumetric
Support components	Visual
Valve body welds	Volumetric (Surface as required)
Valve bodies	Visual
Exempted components	Visual

- Optical rod is used as an extension of the TV system enabling it to examine surfaces at places inaccessible to the TV head
- Magnification optical device for small size bottoms.
- Surface replication for defect depth measurement

Volumetric examination

- Ultrasonic is used to establish both the length and depth of flaws

Surface examination

- Liquid penetrant method is used for welds examination

RESULTS AND ANALYSIS

The results of ISI of the reactor tank and spent fuel storage can be stated as follows:

1. The reactor aluminum structures have only pitting as a major defect sue to chlorine- ions concentration. The detected pits and less than 0.01 mm/year corrosion are allowable damages which practically have no effect on the strength and do not prevent the operation of the reactor tank and intrareactor structures.
2. For the spent fuel storage large areas of inner surface are covered by strips and pits, besides that the bottom is not accessible due to lattice design and large quantity of the deposits. So no certain decision on a serviceability on the spent fuel storage tank .

CONCLUSIONS AND RECOMMENDA TIONS

From what followed, we may conclude the following:

1. The ISI of the reactor tank of ETRR-1 revealed that the metal surface is mainly exposed to pitting. The number and size of pits do not prevent the operation of the reactor under normal water and chemical conditions.
2. For the spent fuel storage tank, the decision can be taken after additional survey when the fuel will be removed, and the bottom could be cleaned. So, based on the obtained ISI results, the ETRR-1 reactor can be operated safely with the same capacity.

For safe and reliable operation it is necessary to carry out the following :

- Setting up an efficient system of water treatment.
- Installing an efficient system of water purification at the primary circuit.
- Carrying out annual ISI of the metal condition.
- Providing a new spent fuel storage with independent system of water purification

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