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Implementation of Risk Based Inspection (RBI) to Determine Ammonia Factory Inspection Planning PT. Pupuk Kaltim TBK

Alfino Alwie, ErryRimawan
Mechanical Engineering Department, Faculty of Industrial Technology (FTI), Universitas Mercubuana
Jl. Meruya Selatan, Kebon Jeruk, Jakarta Barat

Abstract:- Inspection program is an important maintenance activity in industrial processes, the risk based inspection (RBI) methodology is commonly used for the inspection of pressurized fixed equipment, including pressure vessel, piping, tankage, and heat exchanger in the refining and petrochemical, and chemical process plant. The RBI provides the basis for marking informed decisions on inspection frequency, the extent of inspection, and the most suitable type of Nondestructive Evaluation (NDE). A Priority of Inspection is based on risk level causing equipment failure either leakage or breakage that can be described with expected values and lead to impacts on human safety, environment, loss of corporate and business assets, is the integrity of the likelihood and co efficiency of equipment failure. In this paper describes the RBI methodology which reflects the values of risk. An example of an implementation of Fertilizer Ammonia Plant in Kalimantan-Indonesia will be featured and discuss the suggested approach.

***Keywords**:- Risk, Inspection, Microsoft Excel, Weibull Distribution, RBI, Reliability, Probability of Failure.*

I. INTRODUCTION

Inspection is generally used in industrial processes to reduce the risk associated with failure of pressurized system equipment, such as pressure vessel and piping. The inspection is important when high readiness and performance are to be achieved, but preventive maintenance, such as inspection is expensive and a relatively large contribution of total operational costs. Inspection is a direct cost and is very similar with preventive maintenance to avoid failure. The maintenance planning is to give a balance between all this.

To assist the decision makers for their planning and checks, different types of tools and methodologies can be used and available. One of the various tools presented in this paper is the risk based inspection (RBI) methodology, a methodology commonly used in chemical, petrochemical, oil & gas and refinery industries.

Risk Based Inspection (RBI) is an optimal maintenance business process used to examine equipment such as pressure vessels, heat exchangers and piping in industrial plants.

Arisk is examined from losing their durability that is caused bya failure mode either from material damage or external effects such as falling objects. Thr risk is calculated from the probability or rate of failure of the equipment with the consequences of failure in terms of human safety, business loss, and environmental health and safety.

The RBI study begins with developing a methodology that includes probability of failure (PoF), consequence of failure (CoF), and risk matrix creation. In this paper the calculation approach is based on the methodology of API 580 and API 581 for the probabilistic and deterministic approach of ASME Code PV, Section VIII, Div. 1, API 579 Fitness For Service.

II. METHODOLOGY ASSESSMENT

The assessment is divided into several stages, described as follows:

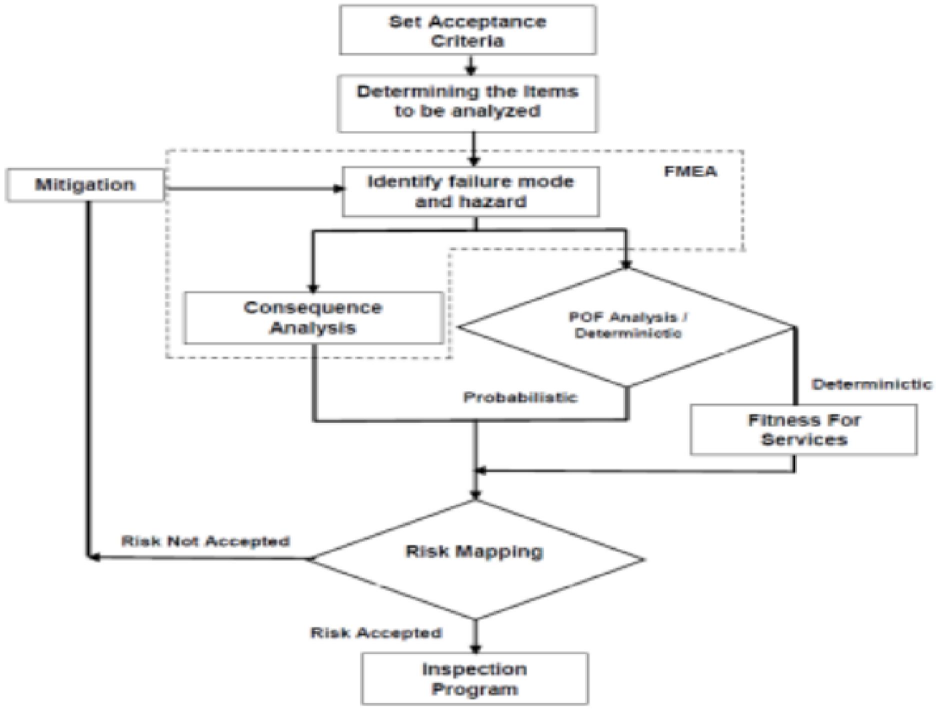

Fig 1:- RBI Assessment Process Flowchart

III. ACCEPTANCE CRITERIA

Severity Level	Description	Definition	Acceptable POF (/year)
I	Catastrophic	Multiple Fatalities, Catastrophic environmental impact	$<10^{-5}$
II	Major	Death of one company or associated person, Severe Injury, Major environmental impact	10^{-5} - 10^{-4}
III	Moderate	Medical treatment for personnel , Minor reportable environmental incident	10^{-4} - 10^{-3}
IVr	Minor	Minor medical treatment or first aid for Plant personnel, Non reportable environtment incident	10^{-3} - 10^{-2}
V	Insignificant	No safety or environmental consequences	$>10^{-2}$

Table 1:- Acceptance Criteria

IV. IDENTIFY FAILURE MODE

The following is the potential failure modes that occurred at Ammonia Plant Kaltim 1:

- Local / general internal corrosion
- Pitting Corrosion
- Fatigue
- High Temperature Hydrogen Attack (HTHA)
- Stress Corrosion Cracking
- Crack / Flaw

From failure modes that have been defined, a screening analysis will be conducted in order to determine which failure is the largest contributor and will be deciding to the schedule of inspection equipment.

Failure Mode Effects Analysis (FMEA) worksheet is used for qualitative analysis that an appropriate depth of information on the causes of failure, then will be put on a quantitative basis when mathematical failure rate models are combined with a statistical failure mode using weibull distribution.

Cate-gory	Description	Definition	Acceptable POF (/year)
I	Catastrophic	Major production loss, > 40 days or > 72.000 Ton product. Financial impact at corporate level (>USD $ 15.000.000).	$<10^{-5}$
II	Major	Signifcant loss production (≥ 2 days – 40 days) or (≥ 3.600 – 72.000) Ton product. Financial impact at a facility level (>USD $ 1.500.000 – USD $ 15.000.000)	10^{-5} - 10^{-4}
III	Moderate	Loss production capacity (10 – 50 %) for short term (< 2 days) or (> 360 – < 3.600) Ton Product Financial impact at a unit level (>USD $ 150.000 – USD $ 1.500.000)	10^{-4} - 10^{-3}
IVr	Minor	Minor loss of production capacity (<10%) for short term (< 2 days) or (0 – 360) Ton Product (USD $ 15.000 – USD $ 150.000)	10^{-3} - 10^{-2}
V	Insignificant	Process capability not impacted.(< USD $ 15.000) consequences	$>10^{-2}$

Table: 2: Production Acceptance Criteria

Severity Level	Category 1 ($>10^{-2}$)	Category 2 (10^{-3} - 10^{-2})	Category 3 (10^{-4} - 10^{-3})	Category 4 (10^{-5} - 10^{-5})	Category 5 ($<10^{-5}$)
Insignificant	2 item			1 item	21 item
Minor					8 item
Moderate					14 item
Major	6 item	1 item		37 item	66 item
Catastrophic					6 item

Table: 3: Summary of Result

Risk Level	Area
Low	
Medium	
High	

The total amounts of static equipments are 166 item, where 6 item are major, 1 item medium and the others 159 item are low risk.

V. DATA IDENTIFICATION

In RBI implementation, the first step undertaken was to identify and collect data from the equipment that will be examined in RBI. To provide the data needed is just with regard to calculation of the equipment strength (mechanical/structural integrity). whereas the data relating to the needs of the process, not needed in the study of analysis of RBI. The following are the types of data collected in order to conduct the analysis of RBI:

A. Design data such as: types and strength of material, geometry (diameter, thickness, corrosion allowance), coating (if available)

B. Operational data that consist of normal operation pressure and temperature, corrosion rate, fluid composition.

C. Maintenance data, such as: failure modes, inspection data (NDT).

VI. ASSESSMENT PROBABILITY OF FAILURE (PoF)

In conducting the assessment, the PoF is divided into two approaches, there are:

➢ Qualitative approach, that is the approach based on engineering judgment and experience. This approach is selected if the following conditions occur:

- Historical data failure less than 3 data
- Lack of supporting data for deterministic analysis
- Failure prediction of High Temperature Hydrogen Attack (HTHA)
- Prediction Of Stress Corrosion Cracking

A qualitative approach to predict the failure of High Temperature Hydrogen Attack (HTHA) refer to Re-commended Practice per API RP 581 based on the content of the partial pressure of hydrogen, temperature and material. The following are the parameters used in the prediction HTHA:

$$Pv = \log(PH_2) + 3.09 \times 10^{-04} (T) \times (\log(t) + 14) \quad (1)$$

Where,

PH_2 = hydrogen partial pressure

T = Operating conditions temperature upset (°K)

t = Duration of upset conditions (hours).

2. Quantitative approach, that is the approach based on the calculation of statistical analysis against the historical failure happens. This approach is used if the following conditions occur:

- It has a historical failure data more than 3
- has data thickness NDT inspection results

VII. WEIBULL ANALYSIS

Quantitative probabilistic method relies heavily on the availability of data. From the results of previous assessment screening, probabilistic quantitative approaches using Weibull analysis is selected to predict the failure of tube applied quantitatively. Probabilistic analysis for the life data analysis using Weibull distribution is very commonly used

The hallmarks of this analysis because the Weibull distribution can provide a level of confidence (confidence level) high enough to predict a trend of failures, though with the amount of data that is a little, compared to other distributions such as the normal distribution, lognormal, and others.

In General, the equation for the Weibull Cumulative PoF is as follows:

$$F(t)=1-\exp[-\left(1+\frac{t}{\eta}\right)^{\beta} \quad (1)$$

Where:

F(t)= Cumulative PoF per unit of time

T = elapsed in-service time

β = Shape Factor

η= Scale Factor

In the calculation, Weibull analysis spreadsheet program Microsoft Excel used as tools. It can be expressed as follows:

$$\beta.\ln(t) - \beta.\ln(\eta) = \ln\left[\ln((1-F(t))\right] \quad (2)$$

and then will be expressed as y(t) = mt + C, where:

$$y = \ln\left[\ln(1-F(t)\right] \quad (3)$$

$$m = \beta$$
$$t = \ln(t)$$
$$C = -\beta.\ln(\eta)$$

In the graph on the Weibull distribution, spreadsheets can be described as follows:

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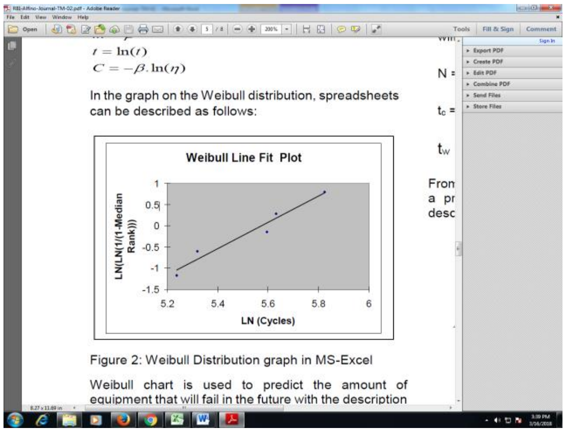


Fig 2:- Weibull Distribution graph in MS-Excel

Weibull chart is used to predict the amount of equipment that will fail in the future with the description as follows:

Dimana,

P(x) = p = the number of tube that has failed

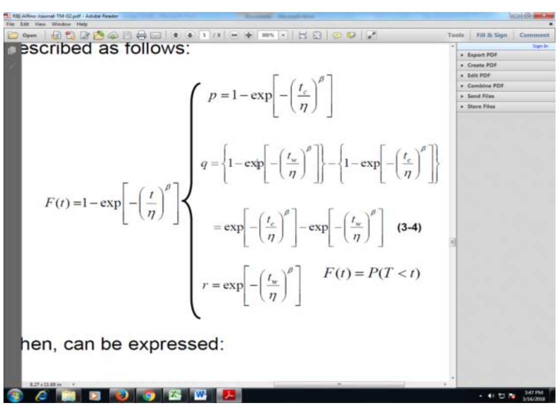
P(y) = q = The number of tube that is predicted will fail

N = The total number of tube

t_c = Time duration in-service now

t_w = The duration of time from now to the future

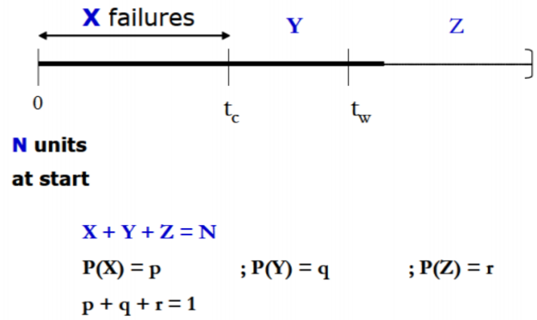
From the figure 3 and equation 1 can be derived to get a prediction of failure time data in tube that are described as follows:


escribed as follows:

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right] \begin{cases} p = 1 - \exp\left[-\left(\frac{t_c}{\eta}\right)^{\beta}\right] \\ q = \left\{1 - \exp\left[-\left(\frac{t_w}{\eta}\right)^{\beta}\right]\right\} - \left\{1 - \exp\left[-\left(\frac{t_c}{\eta}\right)^{\beta}\right]\right\} \\ \quad = \exp\left[-\left(\frac{t_c}{\eta}\right)^{\beta}\right] - \exp\left[-\left(\frac{t_w}{\eta}\right)^{\beta}\right] \quad \textbf{(3-4)} \\ r = \exp\left[-\left(\frac{t_w}{\eta}\right)^{\beta}\right] \quad F(t) = P(T < t) \end{cases}$$

hen, can be expressed:

Then, can be expressed: (4)



(5)

Fig 3:- The Failure Prediction of Equipment Illustration

Where:

q = PoF tube that fails in the future

Y = the number of predictions the tube will fail in the future

N = the total number of tube

VIII. DETERMINISTIC APPROACH

Deterministic approach will be done if a probabilistic approach does not allow to apply. This approach tends to be more conservative, the result has a safety margin is more relatively high from the probabilistic approach. This approach will be implemented when the probability data is not very accurate or the confidence level is low.

As an example: when the in service data such as inspection reports are not available. Instead, the design data can be used and certainly will provide a more secure due to the design parameters are higher than actual operating parameters that is typically used in probabilistic approaches.

With respect to the lack of data on the rate corrosion, where the majority of the shell and tube does not have an accurate corrosion rate data or is not available, then the deterministic analysis approach is preferred to simulate the conditions of the equipment side of mechanical integrity. On the deterministic approach, analysis modeling criteria is divided into two, the first is the calculation of the remaining strength that the deciding factor is the thinning process caused by the corrosion process as an exmple: general, local, or pitting. corrosion. If the wall thickness measurement data available, then the full Simulation model FEA will model the local metal loss against conditions of the surrounding area, where the Stress Concentration Factor, Kt can be seen its value. The following example for NH3 Storage (F-3001) Finite Element Model (FEA), which has a wall thickness data results of NDT.

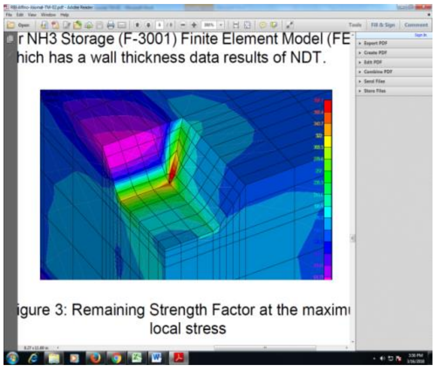


Fig 4:- Remaining Strength Factor at the maximum local stress

If data thickness measurement is not available, then the equipment is assumed to metal loss in general. In other words, all locations on the shell has the same condition for metal loss. So the effect of the geometry of the equipment will greatly determine the condition of their strength. That became the focus of this approach is the output in areas near the nozzle which would tend to give the results of calculation of higher stress from other areas.

The following is an illustration of the approach:

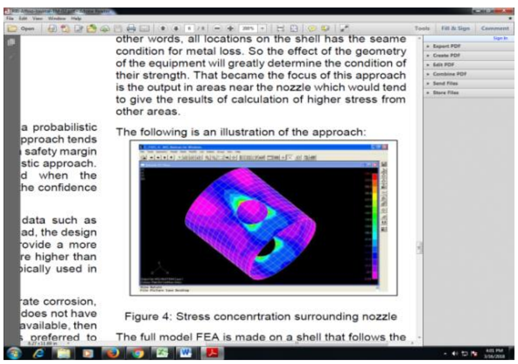


Fig 5:- Stress concentration surrounding nozzle

The full model FEA is made on a shell that follows the image dimensions of the construction drawing and input the corrosion rate factors with assuming a thickness reduction of the corrosion that is derived from a corrosion allowance against to in-service time.

The results of modelling obtained load distribution / stress due to the contours of the internal pressure on the entire surface of the shell.

IX. REMAINING STRENGTH FACTOR EXPRESSION

Definition of residual strength is derived from the calculation of the Remaining Strength Factor (RSF), that is Ultimate Tensile Strength comparison between (UTS) with Maximum Von Mises Stress that occurs in the shell. In mathematical expressions, can be written as follows:

$$RSF = \frac{UTS}{S_{VMmax}} \qquad (6)$$

Failure criteria is stated when RSF≤ 1. This means that stress happens will exceed the strength of the material.

X. FATIGUE ANALYSIS

The fatigue analysis equation can be studied by Miner's Rule defined as follows:

$$D = \sum_{i=1}^{n} \frac{n_i}{N_i} \qquad (7)$$

Where;
D = Cumulative Damage
ni = number of cycles that occur in level stress i
Ni = number of fatigue cycles at Stress level i based on material testing

This analysis is used to predict life of the shell. A screening process is conducted toscreening that is the amount of stress occurs, whether it is derived by analytical calculation of hoop stress combined with certain Kt quantity, or derived based on full model FEA. Fatigue load calculation modeling is based on normal operating conditions where fluctuation of loading is assumed to fluctuate about 10% of the average load. Therefore, it is necessary to define the normal operating load spectrum consisting of:

- Spectrum-startup-normal operation-shutdown, the normal load spectrum of the operation is determined based on the operating loading cycle starting from the startup-normal shutdown-operation.
- Spectrum load at startup and shutdown, For a conservative approach, increase the pressure load at startup that isconsidered directly increased from 0% to reach at a maximum of 100% normal operating pressure and back to 0%.

The assumption above will give more conservative loading results, if is compared to the gradual loading of startup.

- Spectrum normal load operation, under normal operating conditions, the amount of pressure that is assumed will refer to the maximum normal operating pressure, while the intensity (repetition) of the normal pressure load can be obtained from the measurement of operating parameters. Conservative modeling of this operating expense assumes that fluctuations in pressure loads occur at 10% of the normal operating load. For example, if the maximum actual operating pressure load is 250 kg / cm2, then it is assumed that the load fluctuation is about 10% of the load range, so the load fluctuation simulation occurs in the range of 237.5 kg / cm2 - 262.5 kg / cm2.

- Fluctuation intensity normal load operation, the standard maximum frequency standard per ASME for lowcycle fatigue load is 1 Hz. The following figure 6 is a picture of load spectrum under Startup- Normal Operating PressureShutdown

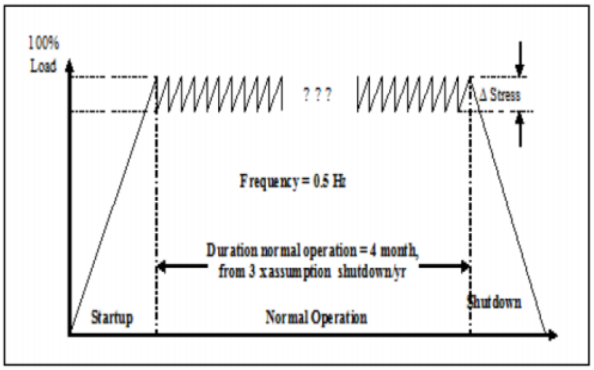


Fig 6:- Illustration Spectrum pressure Startup-ops-shutdown

- Fracture mechanics, this analysis will apply to tubes that do not have Eddy Current Test measurements or do not have historically sufficient failure to allow probabilistic analysis. This modeling uses the spectrum of loading from the normal operation similar to the fatigue analysis in figure 5. The modeling of this analysis using NASGRO program with initial fracture scenario is surface, embedded, and semi-elliptical crack on base metal tube inside. In this example, if the tube material is ASTM 213 TP, then the material data to be used is ASTM 200 Series available in NASGRO databank program.

Life Fraction Rule analysis described as follows:

$$D = \sum \frac{n_i}{N_i} + \sum \frac{t_i}{T_i} \quad (8)$$

Where :
ni = Number of cycle at level stress load i
Ni = Fatigue Life per ASME Fatigue Curve
ti = Number of cycle at thermal stress i
T = Rupture Strength

XI. INSPECTION SCHEDULE BASED ON RISK LEVEL

After the risk level of each static equipment, the determination of the inspection schedule is the final step of the RBI process stages. Defining criteria / priority of the inspection schedule shall be carried out. The fo llowing are the criteria / priorities that may affect the inspection schedule:

1. Equipment age that is one of the factors to determine the priority scale for inspection. The older the in its service life, the higher of the priority for inspection schedule

2. Failure history, this will be focused on the calculation of Mean Time Between Failure (MTBF) based on the date of failure. The smaller the MTBF, the higher of the priority for the inspection schedule.

3. Inspection data, the material thickness of the inspection results will provide a higher confidence level. The length or shortness of the subsequent inspection schedule interval will depend on the results of the previous inspection.

4. Corrosion rate, the corrosion rate data can be derived from several sources, i.e: measurement results, literature, or assumptions based on design specifications or engineering judgment.

5. Safety design factor, this factor will be considered if it does not have inspection data, where the concept of design is usually based on the designer has experience or the results of studies conducted before the design stage of design.

6. Fluid service, the properties of the fluid that becomes the process mediawill be reviewed from its hazardous nature (especially its flammable and toxicity properties). This study is a factor in the Consequence / Severity Ranking process using the FMEA method.

7. Suspected Occurrence of Stress Corrosion Cracking (SCC), the priority inspection will be higher with the potential occurrence of SCC, especially in upset operation condition.

8. Suspected Occurrence of HTHA, this will raise the priority of inspection scheduling if HTHA suspicion will occur, especially in upset conditions where the potential excess hydrogen appears in this condition.

The classification of the maximum Inspection Interval was defined under the following conditions:

➢ Shell and head section, The classification of the maximum Inspection.

- Priority 1, i.e: scheduling at turn around (TA) / up / time for the following conditions interval is defined under the following conditions:
  i. Severity Ranking: Major or Catastrophic, no previous inspection has been performed, and has a Security / RSF Factor <2
  ii. Leakage history / failure, have MTBF <5 years

iii. The corrosion rate is unknown, does not have data corrosion monitoring, nor has corrosion rate> 10 mpy

1. Priority 2, which is the scheduling of a 5-year periodic inspection period adjusted to the upcoming TA interval for the following conditions:

   i. Previously inspected, and has a Security / RSF Factor: 2 <RSF <3, never have a leak history / failures
   ii. Corrosion rate: 5 < CR < 10 mpy

2. Priority 3, which is scheduling the 10-year inspection period by adjusting the interval scheduling, i.e: have Severity: insignificant and minor, low corrosion rate < 5 mpy, never have a leak history.

XII. CONCLUSION

RBI is powerfull tools to determine inspection schedule and also can reduce the total inspection cost, but RBI is extremely depend upon the plant historical data of equipment failure or corrosion rate. If the data are not enough available and very struggling to determine the risk. The semi-quantitative approach is normally used in industry at the moment.

REFERENCES

[1]. API RP 579 “Fitness For Services”. 2000
[2]. API RP 581 “Risk Based Inspection-Based Resource Document ”. 2000
[3]. ASME BPV SECTION VIII, DIV. I. 2002
[4]. ASME BPV SECTION II D. 2002
[5]. FATIGUE CRACK GROWTH COMPUTER PROGRAM “NASGRO” VERSION 3.0. Reference Manual. 2002
[6]. Atlas of Crepp and Stress-Rupture Data”. Handbook. ASM International. 1988 BS EN ISO 17776:2002, Guidelines on tools and techniques for hazard identification and risk assessment