EFFECTIVE TRIBOLOGICAL TECHNIQUE TO REDUCE RISK & INCREASE RELIABILITY OF NUCLEAR POWER PLANT

Amit Kumar Jain
Research Scholar, Department of Mechanical Engineering
M.A.N.I.T Bhopal India
amitkumarjain05@gmail.com

Amit Suhane
Assistant Professor, Department of Mechanical Engineering
M.A.N.I.T Bhopal India
amitsuhane2003@yahoo.co.in

ABSTRACT- **In India, Nuclear power is the fourth-largest and important source of electricity after thermal, hydroelectric and other available sources. The raw material for such source of energy is limited on earth and therefore to achieve efficient business operations in terms of electricity generation, the cost efficiency of nuclear power plant must therefore be improved by utilizing the suitable tribological techniques. Efficient functioning of the large variety of mechanical equipment used in NPP's (Nuclear Power Plants) is essential for the safe operation of the plant. The risks associated with nuclear power plants are pretty scary. For this maintaining operating plants effectively is very important, and this can be achieved by the development of new technologies of CBM to make currently operating plants capable of operating over the long term in a stable and highly reliable manner.**

This paper explains the ways to improve maintenance and reduce expenses and downtime losses by using simple, low cost condition monitoring methods by the Implementation of an effective tribological technique, a case of Condition Based Maintenance.

Keywords: Nuclear power plant (NPP), Condition-Based Maintenance (CBM), Risk, Maintenance, Tribology.

I. INTRODUCTION

1.1 *Significance:* The nuclear power plant, located in India, represents a significant milestone in the technological and economic development of the Country.

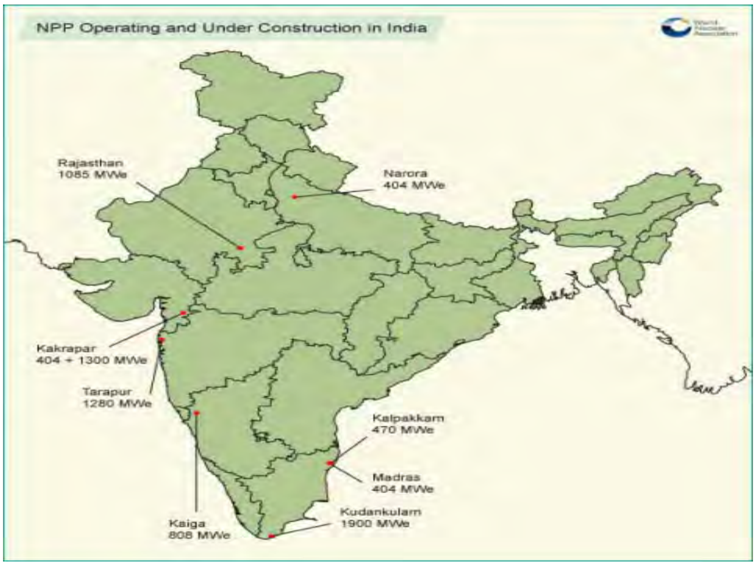

Figure.1 (NPP'S in India.)

India has a flourishing and largely indigenous nuclear power program and expects to have 14,600 MWe nuclear capacity on line by 2020 and 27,500 MWe by 2024. It aims to supply 25% of electricity from nuclear power by 2050. India has a vision of becoming a world leader in nuclear technology due to its expertise in fast reactors and thorium fuel cycle. Electricity demand in India is increasing rapidly, and the 900 billion kilowatt hours produced in 2009 was more than triple the 1990 output, though still represented only some 750 kWh per capita for the year. With huge transmission losses, this resulted in only about 650 billion kWh consumption. Coal provides 68% of the electricity at present, but reserves are limited. Gas provides 12%, hydro 12%. The per capita electricity consumption figure is expected to double by 2020, with 6.3% annual growth, and reach 5000-6000 kWh by 2050, requiring about 8000 TWh/yr then [1].

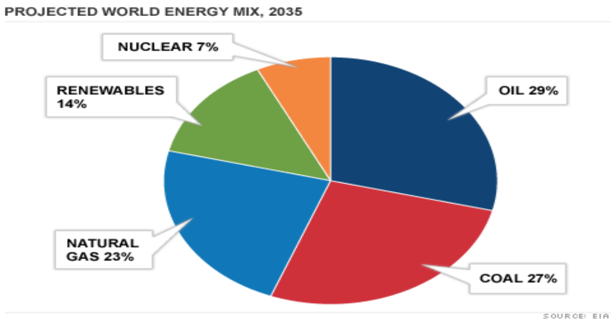

Figure. 2 (World Energy Ratio)

1.2 *Historical review:* As of 2010, India has 20 nuclear reactors in operation in six nuclear power plants, generating 4,780 MW [2] while seven other reactors are under construction and are expected to generate an additional 5,300 MW [3]. In October 2010, India drew up "an ambitious plan to reach a nuclear power capacity of 63,000 MW in 2032"[4], India has been making advances in the field of thorium-based fuels, working to design and develop a prototype for an atomic reactor using thorium and low-enriched uranium[5]. India now envisages increasing the contribution of nuclear power to overall electricity generation capacity from 2.8% to 9% within 25 years [6]. By 2017, India's installed nuclear power generation capacity will increase to 10,080 MW [7]. As of 2009, India stands 9th in the world in terms of number of operational nuclear power reactors. Indigenous atomic reactors include TAPS-3, and -4, both of which are 540 MW reactors [8]. India's US$717 million fast breeder reactor project is expected to be operational by 2012-13[9]. The Indian nuclear power industry is expected to undergo a significant expansion in the coming year's thanks in part to the passing of the U.S.-India Civil Nuclear Agreement. This agreement will allow India to carry out trade of nuclear fuel and technologies with other countries and significantly enhance its power generation capacity. When the agreement goes through, India is expected to generate an additional 25,000 MW of nuclear power by 2020, bringing total estimated nuclear power generation to 45,000 MW [10]. Countries such as France produce approximately 90 percent of their electricity from nuclear power and lead the world in nuclear power generating technology proving that nuclear power is an economic alternative to fossil fuel power stations.

1.3 *Recent nuclear power developments in India:* The Tarapur 3&4 reactors of 540 MWe gross (490 MWe net) were developed indigenously from the 220 MWe (gross) model PHWR and were built by NPCIL. The first - Tarapur 4 - was connected to the grid in June 2005 and started commercial operation in September. Tarapur-4's criticality came five years after pouring first concrete and seven months ahead of schedule. Its twin - unit 3 - was about a year behind it and was connected to the grid in June 2006 with commercial operation in August, five months ahead of schedule. Tarapur 3 & 4 cost about $1200/kW, and are competitive with imported coal. Future indigenous PHWR reactors will be 700 MWe gross (640 MWe net) [11]. The first four are being built at Kakrapar and Rajasthan. Kudankulam: Russia's Atomstroyexport is building the country's first large nuclear power plant, comprising two VVER-1000 (V-392) reactors, under a Russian-financed US$ 3 billion contract. A long-term credit facility covers about half the cost of the plant. The AES-92 units at Kudankulam in Tamil Nadu state are being built by NPCIL and will be commissioned and operated by NPCIL under IAEA safeguards [12]. Kaiga 3 started up in February, was connected to the grid in April and went into commercial operation in May 2007. Unit 4 started up in November 2010 and was grid-connected in January 2011, but is about 30 months behind original schedule due to shortage of uranium. The Kaiga units are not under UN safeguards, so cannot use imported uranium. Rajasthan-5 started up in November 2009, using imported Russian fuel, and in December it was connected to the northern grid. RAPP-6 started up in January 2010 and was grid connected at the end of March. Both are now in commercial operation.

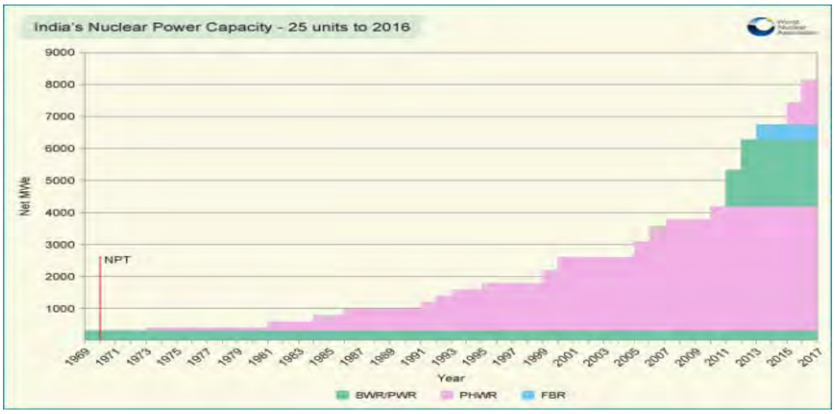

Figure. 3 (India Nuclear Power Capacity)

1.4 Issues dealing with NPP's: In addition to providing a stable supply of electric power, nuclear power plants are called upon to reduce the cost of generating that power. In this regard, important issues in a maintenance plan for an operating plant are:
(1) Stable and continuous operation,
(2) Cost reductions in operation and maintenance (O&M)
(3) Improved facility reliability.
This can be achieved by performing effective CBM.
Radioactive Waste Management in India: Radioactive wastes from the nuclear reactors and reprocessing plants are treated and stored at each site [13]. Waste immobilisation plants are in operation at Tarapur and Trombay and another is being constructed at Kalpakkam [14]. Research on final disposal of high-level and long-lived wastes in a geological repository is in progress at BARC.

Regulation and safety: The Atomic Energy Commission (AEC) was established in 1948 under the Atomic Energy Act as a policy body. Then in 1954 the Department of Atomic Energy (DAE) [15] was set up to encompass research, technology development and commercial reactor operation. The current Atomic Energy Act is 1962, and it permits only government-owned enterprises to be involved in nuclear power. The DAE includes NPCIL, Uranium Corporation of India Ltd (UCIL, mining and processing), Atomic Minerals Directorate for Exploration and Research (AMD, exploration), Electronics Corporation of India Ltd (reactor control and instrumentation) and BHAVINI (Bhartiya Nabhikiya Vidyut Nigam Ltd) for setting up fast reactors. The DAE also controls the Heavy Water Board for production of heavy water and the Nuclear Fuel Complex for fuel and component manufacture. The Nuclear Safety Regulatory Authority Bill was drawn up in response to events at Fukushima and aims to establish several new regulatory bodies.

II. NUCLEAR POWER PLANTS LAYOUT

The figure below illustrates the schematic layout of a nuclear power plant [16].

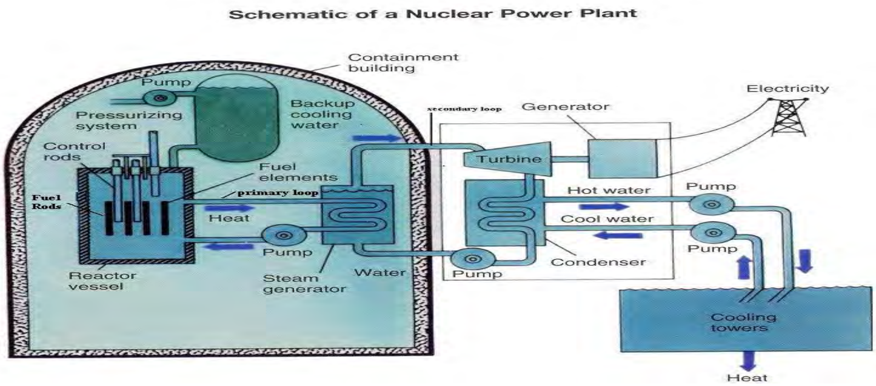

Figure. 4 (Schematic Layout of a NPP)

2.1 *Nuclear power plant components:* The key components common to most types of nuclear power plants are [17]:

- Nuclear fuel
- Nuclear reactor core

- Neutron moderator
- Neutron poison
- Neutron howitzer (provides steady source of neutrons to re-initiate reaction following shutdown)
- Coolant (often the Neutron Moderator and the Coolant are the same, usually both purified water)
- Control rods
- Reactor vessel
- Boiler feed water pump
- Steam generators (not in BWRs)
- Steam turbine
- Electrical generator
- Condenser
- Cooling tower (not always required)
- Radwaste System (a section of the plant handling radioactive waste)
- Refuelling Floor
- Spent fuel pool
- Nuclear safety systems
    - Reactor Protective System (RPS)
    - Emergency Diesel Generators
    - Emergency Core Cooling Systems (ECCS)
    - Standby Liquid Control System (emergency boron injection, in BWRs only)
- Essential service water system (ESWS)
- Containment building
- Control room
- Emergency Operations Facility
- Nuclear training facility (usually contains a Control Room simulator)

2.2 Working: In order to turn nuclear fission into electrical energy, nuclear power plant operators have to control the energy given off by the enriched uranium and allow it to heat water into steam. Enriched uranium typically is formed into inch-long (2.5-centimeter-long) pellets, each with approximately the same diameter as a dime. Next, the pellets are arranged into long rods, and the rods are collected together into bundles. The bundles are submerged in water inside a pressure vessel [18]. The water acts as a coolant. Left to its own devices, the uranium would eventually overheat and melt. To prevent overheating**,** control rods made of a material that absorbs neutrons are inserted into the uranium bundle using a mechanism that can raise or lower them. Raising and lowering the control rods allow operators to control the rate of the nuclear reaction. When an operator wants the uranium core to produce more heat, the control rods are lifted out of the uranium bundle (thus absorbing fewer neutrons). To reduce heat, they are lowered into the uranium bundle. The rods can also be lowered completely into the uranium bundle to shut the reactor down in the event of an accident or to change the fuel. The uranium bundle acts as an extremely high-energy source of heat. It heats the water and turns it to steam. The steam drives a turbine, which spins a generator to produce power. Humans have been harnessing the expansion of water into steam for hundreds of years. In some nuclear power plants, the steam from the reactor goes through a secondary, intermediate heat exchanger to convert another loop of water to steam, which drives the turbine. The advantage to this design is that the radioactive water/steam never contacts the turbine. Also, in some reactors, the coolant fluid in contact with the reactor core is gas (carbon dioxide) or liquid metal (sodium, potassium); these types of reactors allow the core to be operated at higher temperatures.

Nuclear Fission process: In this process heavy nucleus is splitted and release high energy, one fission of U-235 causes 230 mev energy [19].

Nuclear chain Reaction: When a neutron hits a U-235 3 neutrons produced [19], “Chain reaction is defined as a fission reaction where neutron from the previous reaction continue to propagate and repeat the reaction”.

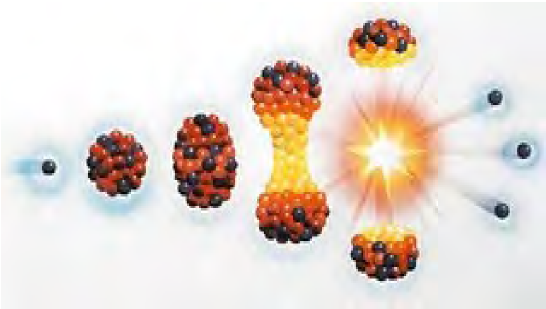

Figure.5 (Nuclear Fission process)

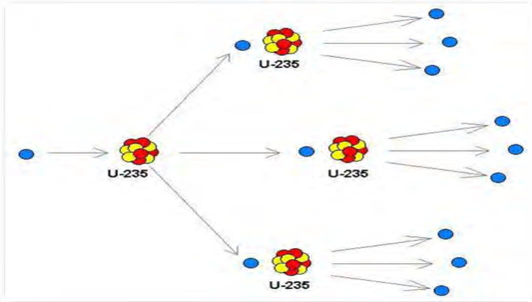

Figure.6 (Nuclear chain Reaction)

2.3 Classification: Several nuclear power plant types are used for energy generation in the world [20]. The different types are usually classified based on the main features of the reactor applied in them. The most widespread power plant reactor types are:

S.No	Type of Nuclear Reactor	Description
1	Light water reactors	Both the moderator and coolant are light water (H_2O). To this category belong the pressurized water reactors (PWR) and boiling water reactors (BWR).
2	Heavy water reactors (CANDU)	Both the coolant and moderator are heavy water (D_2O).
3	Graphite moderated reactors	In this category there is gas cooled reactors (GCR) and light water cooled reactors (RBMK).
4	Exotic reactors	Fast breeder reactors and other experimental installations.
5	New generation reactors	Reactors of the future.

Table 1 (Nuclear Power Plant Reactor Types)

2.4 Advantages:

- Nuclear power production is a type of power which is environmentally friendly and clean. Almost zero emissions (very low greenhouse gas emissions). In a world that faces global warming it is suggested that increasing the use of nuclear power is the only way of protecting the environment and preventing catastrophic climate change [21]. A small amount of matter creates a large amount of energy, so lot of energy is generated from a single power plant.
- The amount of electricity produced in a nuclear power station is equivalent to that produced by a fossil fuelled power station. Nuclear power stations do not burn fossil fuels to produce electricity and consequently; they do not produce damaging, polluting gases.
- Nuclear reactors can be manufactured small enough to power ships and submarines. If this was extended beyond military vessels, the number of oil burning vessels would be reduced and consequently pollution. They can be sited almost anywhere unlike oil which is mostly imported.
- The plants almost never experience problems if not from human error, less man power requirement. Modern reactors have two to ten times more efficiency than the old generation reactors. New reactor types have been designed to make it physically impossible to melt down. As the core gets hotter the reaction gets slower, hence a run-away reaction leading to a melt-down is not possible. Breeder reactors create more usable fuel than they use [22].

2.5 Variables & Risk Associated:

- Nuclear power plants are more expensive to build and maintain, it is considered that nuclear power is a controversial method of producing electricity. Environmental organisations are very concerned about the radioactive fuel it needs. There have been serious accidents with a small number of nuclear power stations. The accident at Chernobyl (Ukraine) in 1986 [23], led to 30 people being killed and over 100,000 people being evacuated. In the preceding years another 20,000 people were resettled away from the radioactive area. Radiation was even detected over a thousand miles away in the UK as a result of the Chernobyl accident. It has been suggested that over time 2500 people died as a result of the accident.
- There are serious issue regarding the storage of radioactive waste produced through the use of nuclear power. Some of the waste remains radioactive (dangerous) for thousands of years and is currently stored in places such as deep caves and mines. Storing and monitoring the radioactive waste material for thousands of years has a high cost.

- Nuclear powered ships and submarines pose a danger to marine life and the environment. Old vessels can leak radiation if they are not maintained properly or if they are dismantled carelessly at the end of their working lives.
- Human life and Environment near the nuclear power stations or waste storage depots are concerned about nuclear accidents and radioactive leaks. Some fear that living in these areas can damage their health, especially the health of young children. Mishaps at nuclear plants can render hundreds of square miles of land uninhabitable and unsuitable for any use for years, decades or longer, and kill off entire river systems. Mishaps at nuclear plants can render hundreds of square miles of land uninhabitable and unsuitable for any use for years, decades or longer, and kill off entire river systems.
- Waste products are dangerous and need to be carefully stored for long periods of time. The spent fuel is highly radioactive and has to be carefully stored for many years or decades after use. This adds to the costs.
- Nuclear power plants can be dangerous to its surroundings and employees. It would cost a lot to clean in case of spillages. There exist safety concerns if the plant is not operated correctly or conditions arise that were unforeseen when the plant was developed, as happened at the Fukushima plant in Japan(2011) [24]; the core melted down following an earthquake and tsunami the plant was not designed to handle despite the world's strongest earthquake codes.

2.6 Safety of Nuclear Power Plants: The general regulations for the safety of nuclear power plants, the systems, structures and components important to safety shall be designed, manufactured, installed and operated so that their quality level and the inspections and tests required to verify their quality level are adequate considering any item's safety significance.
Machinery and equipment: The manufacturer shall have a maintenance programme for manufacturing machines and equipment. Their faultless operation shall be ensured by regular testing. The test results shall be recorded.
Inspection and testing: Employ competent and qualified personnel for manufacturing-related inspection, testing and control. The inspection, measurement and testing equipment shall be regularly checked and calibrated. The results shall be recorded. An approved quality control programme and inspection plans shall be followed in the inspection and testing of equipment or structures.

2.7 The Risk of Nuclear Accidents: We have to rely on prediction and probability analysis to help us estimate the risk of accidental releases from nuclear power plants. Some components of the calculation are highly uncertain, some of the possibilities that have to be taken into account are very unlikely indeed, and some factors (including extremes of human aberration) are of their nature very hard to estimate.

Human errors in operation or maintenance of a plant, though also taken into account in the risk figures, require a different method of control. Some human intervention is required even in a highly automatic system, because although people may make mistakes, they also have a capacity unparalleled by machines, to operate skilfully and make correct judgements in unprecedented situations. This unique human capacity has to be preserved, while deliberately making harmful intervention [25] as difficult as possible.

III. MAINTENANCE STRATEGIES PRACTICED

3.1 Role of Maintenance: Effective maintenance is essential for the safe operation of a nuclear power plant.A large part of the operating cost in industry comes from maintenance of equipment and machines. The cost of maintenance in the United States was estimated to rise from $600 billion in 1981 to $1.2 trillion in 2000 [26]. It is estimated that one third of these costs are due to inefficient management of maintenance. Therefore large savings can be made by increasing the efficiency of maintenance operations in industry. Maintenance can also be seen as an investment in availability and reliability of the equipment. This will further increase the profit. An optimal maintenance schedule can reduce the cost of keeping the machine running as well as increasing its reliability and availability. Cost Effective Maintenance Management is a goal for many companies. An obvious step to achieving cost effective maintenance includes selecting the appropriate maintenance strategy.

3.2 Variety of Strategies: There are various types of maintenance strategies; a broad classification is shown in figure 7.

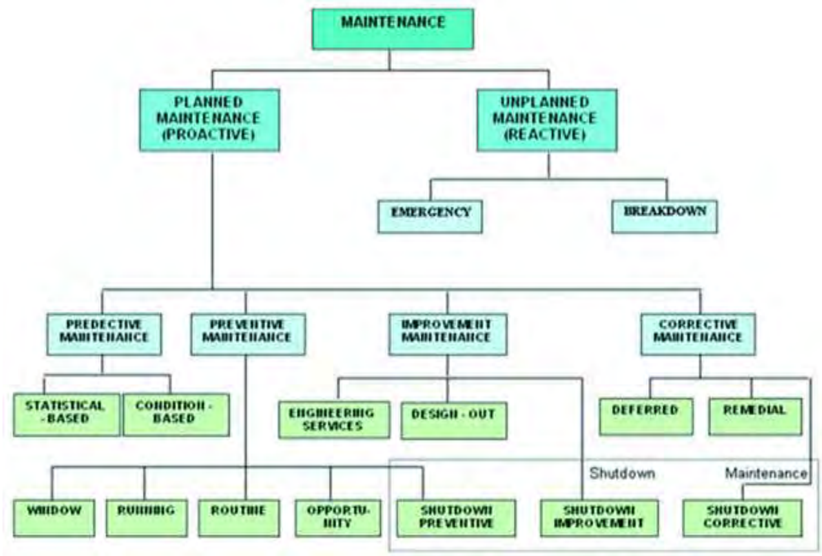

Figure.7 (Variety of Maintenance Strategies)

3.3 The Strategies Practised: Past and current maintenance practices in both the private and government sectors would imply that maintenance is the actions associated with equipment repair after it is broken. The dictionary defines maintenance as follows: "the work of keeping something in proper condition; upkeep." This would imply that maintenance should be actions taken to prevent a device or component from failing or to repair normal equipment degradation experienced with the operation of the device to keep it in proper working order. The need for maintenance is predicated on actual or impending failure – ideally, maintenance is performed to keep equipment and systems running efficiently for at least design life of the component(s).

Reactive Maintenance: It is basically the "run it till it breaks" maintenance mode. No actions or efforts are taken to maintain the equipment as the designer originally intended to ensure design life is reached.
Preventive Maintenance: Actions performed on a time or machine-run-based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level.

Predictive Maintenance: Measurements that detect the onset of system degradation (lower functional state), thereby allowing causal stressors to be eliminated or controlled prior to any significant deterioration in the component physical state. Results indicate current and future functional capability. Basically, predictive maintenance differs from preventive maintenance by basing maintenance need on the actual condition of the machine rather than on some preset schedule.

Condition based maintenance (CBM): One of the most cost effective maintenance strategies is condition based maintenance. However it still requires structured implementation and careful management. Condition based maintenance has been described as a process that requires technologies and human skills that integrates all available equipment condition indicators (diagnostic and performance data, operator logged data, maintenance histories, and design knowledge) to make timely decisions about maintenance requirements of important equipment. It refers to a set of tasks performed to detect incipient failures of equipment, to determine the maintenance actions required, and to restore equipment to its operable condition after detection of an incipient failure condition.

Condition based maintenance leads not only to a reduction of unnecessary preventive maintenance actions and in shifting some maintenance operations away from the outage period (on-line maintenance) but ensures that actions are performed when justified by component/equipment condition [27].

Goal and Significance of CBM: The goal of condition based maintenance is to perform maintenance only upon evidence of need [28]. Condition based maintenance assumes that equipment failure modes will follow one or more of the classical degradation styles and that there is sufficient local knowledge of the equipment's historical performance to perform an extrapolation of its remaining life. This in itself is a form of prognostics based partially on science, and partially on elicited experience of the plant staff. These measurement techniques, observations, tests, and operator intuitions are what forms the plant's condition based maintenance programme.

The objective of condition based maintenance is to optimize reliability and availability by determining the need for maintenance activities based on equipment condition. Using condition monitoring, and observations can be used to project forward in an effort to establish the most probable time of failure and this act to enhance the ability of the plant to plan and act in a proactive manner. CBM assumes that equipment has indicators that can be monitored and analyzed to determine the need for condition directed maintenance activities. Condition based maintenance allows for the most effective maintenance programme by determining the appropriate activity at the correct time taking into the considerations the economic feasibility. Whereas, preventive maintenance assumes operating time as key factor in determining the probable condition of equipment. In the absence of close relationship between operating time and the need for maintenance, these preventive maintenance activities are often not needed and maintenance resources are wasted. Condition based maintenance is accomplished by integrating all available data to predict impending failure of equipment as well as to avoid costly maintenance. This process depends to a large extent on the ability to recognize undesirable operating conditions as measured by diagnostic monitoring systems. The process also allows equipment to continue operating in an undesirable condition while it is being monitored until maintenance can be scheduled. The primary objectives of an optimized maintenance strategy programme that include predictive and condition based maintenance are:

- Improve availability
- Reduced forced outages
- Improve reliability
- Enhance Equipment Life
- Reduce wear from frequent rebuilding
- Minimize potential for problems in disassembly and reassembly
- Detect problems as they occur
- Save Maintenance Costs
- Reduced repair costs
- Reduced overtime
- Reduced parts inventory requirements

Condition monitoring: It may consist of continuous monitoring (for example, on-line diagnostics used in digital instrumentation systems or turbine generator thrust bearing wear monitoring) using permanently installed instrumentation or activities performed at specified intervals to monitor, diagnose, or trend the functional condition of equipment. The results from this activity support an assessment of the current and future functional capability of the equipment monitored and a determination of the nature and schedule for required maintenance.

Although visual inspections can be very useful, modern condition monitoring generally involves the use of advanced technologies. Nuclear plants have been using condition based maintenance for major structures, systems, and components (SSCs) [29] such as pressure boundary components, containment structure, main turbine generator, and reactor coolant pumps for several decades. Since the late 1980s, heightened focus on reducing operation and maintenance cost has led to a broader use of condition based maintenance for other equipment [30].

Condition Monitoring Techniques: Condition Monitoring techniques include a continuous measure of temperature and pressure at critical areas of lifetime limiting components/equipment to use for calculation of accumulation process of fatigue damage. The most typical of the technologies that can be applied to most of the Nuclear Power plants equipment with prompt results and payback are as follows.

- Tribology.
- Vibration monitoring.
- Acoustic analysis.
- Motor analysis technique.
- Motor operated valve testing.
- Thermography.
- Process parameter monitoring.
- Visual inspections.
- Other non-destructive testing techniques.

It is important to identify which machine condition monitoring technologies the most useful and cost effective will be in achieving your goals and objectives. Each technique is limited to specific types of machinery and is useful in identifying specific types of problems. Each technique also provides different short and long term economic benefits [31].

Tribology & It's Potential

Tribology is the general term that refers to design and operating dynamics of the bearing-lubrication-rotor support structure of machinery [32]. A lubricant is a substance capable of reducing friction, heat, and wear when introduced as a film between solid surfaces. The secondary functions of a lubricant are to remove contaminants and protect the solid surfaces. One of the basic technologies of condition based maintenance is lubricating oil analysis. The reason for this is that lube oil analysis is a very effective tool for providing early warning of potential equipment problems. The goals of oil monitoring and analysis are to ensure that the bearings are being properly lubricated. This occurs by monitoring the condition of both the lubricant and the internal surfaces that come in contact with the lubricant.

As lubricant and machine conditions degrade, the physical properties of the oil and wear/contaminant levels will change. By monitoring and trending these changes over time, and establishing useful limits for acceptable operation, lubricant and equipment problems can be quickly identified and resolved. A key element in determining the root cause of oil-related problems, is the ability to classify the types of wear and contaminants present (both chemical and particulate) and their potential source(s). This requires an understanding of chemical properties of the lubricants being used, the metallurgy of the internal components within the bearing reservoir, and the sources of contamination that can enter the system.

Wear and contamination: It can be classified in different categories, as shown in figure 8.

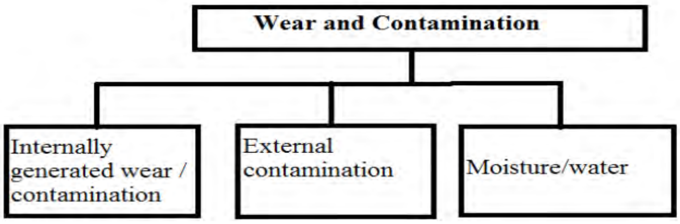

Figure. 8 (Types of wear and contamination)

Internally generated wear / contamination - It can be a combination of ferrous and non-ferrous particles that are generated from bearings, slinger rings, seals, and other internal components that come in contact with the lubricant. In forced oil systems, oil pump wear, filter debris, and particulates from system piping/reservoirs may also be present. The particles generated from internal components can be caused by abrasive wear from metal particles and other contaminants circulating in the system, metal surface fatigue, loss of film thickness/strength, and other fault conditions. They may also chemically interact with the oil itself, causing the formation of insoluble acids. These acids will corrode metal surfaces, deplete additives, and accelerate the chemical breakdown the lubricant.

External contamination - Contamination from airborne particulates (dirt, coal dust, organics), process fluids (Freon, acids), and other external processes are another source of contamination that can affect lubricant and machine condition. These contaminants typically enter lube oil systems from the outside environment through breathers, fill/vent plugs, access covers, and other entry pathways. Typical parameters monitored to assess the amount of external contamination present include Fourier transform – infrared spectroscopy, and elemental levels of silicon, sodium, boron, and potassium. In radiation protection the radioactive contamination is radioactive substances on surfaces, or within solids, liquids or gases (including the human body), where their presence is unintended or undesirable, or the process giving rise to their presence in such places.[33] [34].

Moisture/water - One of most common and damaging sources of contamination is water/moisture. Even at low levels, the presence of water will corrode metal surfaces (i.e. rusting), increase oxidation, and reduce the oil film strength (which can lead to increased wear). There are a variety of sources where water can come from (cooler leaks, seal leaks, condensation), and pathways into the lube oil system (through breathers, access covers, vents, and other openings). Depending on the type and severity of the problem, water may exist in three different states: free water, emulsified water, dissolved water.

Lube oil analysis plays a significant role in assessing contamination levels and managing the condition of the lubricant and machine components [35]. There are two distinct but related areas of concern associated with machinery lubrication: The condition of the lubricant and the condition of the surface lubricated. Both are determined from representative fluid samples obtained in the lubrication system.

Types of Test: There are many tests for lubricant, a broad classification of these tests in shown in figure 9.

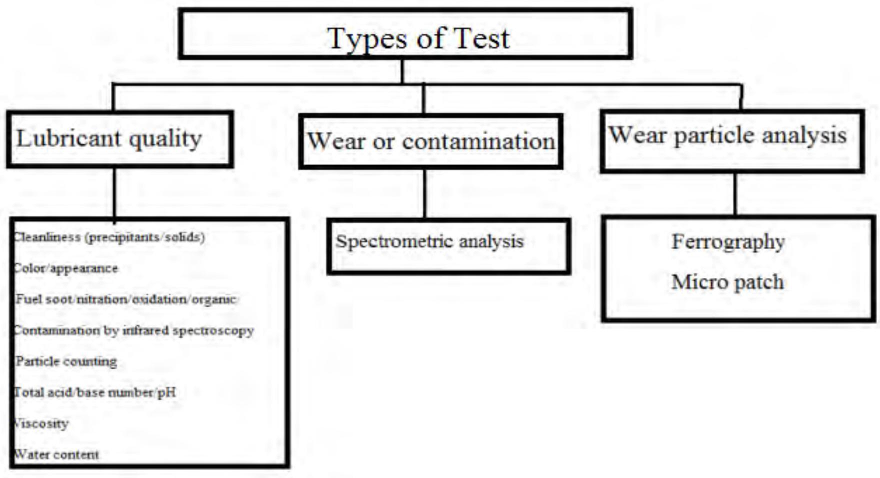

Figure. 9 (Types of test for Lubricant)

The area of oil analysis is covered in the following sections:

- Lubricant quality.
- Particle contamination.
- Wear particle analysis.
- Oil sampling.
- Correlation of technologies.
- Laboratory reports.
- On-site oil testing.

Lubricant quality: Contamination is a leading cause of machinery damage and reduction in the oil's ability to properly perform. By controlling contamination, the life of the lubricant and machine can be extended greatly. Like any good maintenance practice, the earlier a problem is detected, the cheaper it is going to be to correct. After implementing a few good maintenance practices to control contamination, the rewards can be seen almost instantaneously.

There are many possibly sources of contamination with any oil reservoir. New oil is one of the most important areas to consider as a source of potential contamination. When we think of something as being new, we typically think of it as being fresh and clean. Although new oil has not normally been considered as a likely source of contamination, new lube oils are often contaminated. Contamination of new lubricants can happen in a variety of ways. The oil itself may be dirty upon receipt from the supplier. The oil may be dirty as it leaves the refinery or contamination can be introduced during the transportation process. The equipment itself can contribute to sources of contamination. Vents, breathers, filters and seals all offer an avenue of contamination. Vents that are open provide a passage for airborne particles or water. Breathers and filters that are not effectively controlling particles or moisture allow them to enter the system. Similarly, seals that are damaged or not working properly also allow particles or water to enter units. The environment can also be a contributing factor for introduction of contamination.

Particle contamination: Break-in wear, normal wear, and abnormal wear are the three phases of wear that exist in equipment. Break-in wear occurs during the start-up stages of a new component. This phase typically generates significant wear metal debris that will be removed during the first couple of oil changes. Normal wear occurs after the break-in wear stage. During this stage the component becomes more stabilized. Wear metals will increase with equipment usage and decrease when makeup oil is added or oil changes occur. Abnormal wear occurs as a result of some form of lubricant, machinery, or maintenance problem. During this stage the wear metals increase significantly. By using oil analysis on a routine basis, a base line for each piece of equipment can be established. As the oil analysis data deviates from the established base line, abnormal wear modes can be identified. Once abnormal wear modes are identified corrective action can be planned. Implementation of an oil analysis programme with analyses consistent with the goals of the condition based maintenance programme will significantly reduce maintenance costs and improve plant reliability and safety. Lubricant analysis for the purpose of machinery conditioning monitoring is at its best with a significant amount of historical data. It is important to establish a base line for each piece of equipment. All machines generate wear. The key to understanding whether or not a machine is operating properly is to analyze the wear particles being generated from the lubricated surfaces, and correlate this data to the physical condition of the internal components.

Particles can be classified as:

- Ferrous – Magnetic, Paramagnetic, Fe, Fe2O3, Fe3O4, Stainless
- Non-Ferrous – Copper Alloys, Aluminium, Babbitted Metals, Zinc, Chrome, Etc.
- Contaminant – Fluids, Dust, Dirt, External Process, Manufacturing Debris, Filter Material, Friction Polymers, Organic Matter.

Wear particle analysis: Ferrography is a technique that provides microscopic examination and analysis of wear particles separated from all type of fluids. Developed in the mid 1970's as a condition based maintenance technique, it was initially used to magnetically precipitate ferrous wear particles from lubricating oils. This technique was used successfully to monitor the condition of military aircraft engines, gearboxes, and transmissions. That success has prompted the development of other applications, including modification of the method to precipitate non-magnetic particles from lubricants, quantifying wear particles on a glass substrate (ferrogram) and the refinement of our grease solvent used in heavy industry today. Ferrography is also a method of evaluating machine wear condition by examination and evaluation of particles separated from used lubricant samples (oil or grease). The particles are separated by flowing the sample slowly through a high gradient magnetic field, using magnetic force to trap the ferrous debris and gravity to capture the non-ferrous debris.

Oil sampling: Many plants get involved in routine oil sampling and analysis to help reduce the costs associated with maintaining lubrication systems. The most significant costs involve periodic oil changes based on a time schedule as recommended by the equipment specific manufacturer. Recommended oil change frequencies can range from weekly to yearly depending on the equipment, its operating environment, the duty cycle of the equipment, and many other factors. To help reduce and possibly eliminate the need to perform time-based oil changes, a well-designed oil sampling and analysis programme can help. One of the biggest concerns in implementing an oil analysis programme is to determine which equipment should be sampled. For larger systems (greater than 10-15 gallons), it is usually more cost effective to establish a condition based oil change programme, rather than a time based one. For smaller reservoirs (less than 10 gallons), there may or may not be a financial benefit from performing oil analysis versus oil changes. A lot of determination on whether or not to sample smaller reservoirs depends on the criticality of the equipment, and the resultant effects on production or operation, if the equipment or lubrication fails in service. The usefulness of wear particle analysis results depends on how accurate the oil samples are representative of the oil. The most difficult problem encountered in implementing a ferrography programme is procedural control of the oil sampling. Special consideration must be given to location, sampling method, and frequency. While adherence to the following recommendations will not guarantee the securing of representative samples, failure to comply with some or all of them will usually result in the collection of samples that do not represent actual oil conditions.

Laboratory reports: The key to interpreting oil analysis reports is to establish baseline levels for all parameters, and trend the values over time to identify any significant changes. Usually, each oil sample has two reports, one for lubricant condition and one for equipment condition. Because oil analysis is looking at equipment condition on a microscopic level, it often identifies problems earlier in a failure mode than vibration analysis does. Oil analysis also technologies (i.e., the presence of water, incorrect viscosity, and oxidation/chemical breakdown) [36]. It is recommended that a routine testing programme be used in a comprehensive CBM programme. A typical lab report for one oil sample has over fifty different data values from the various tests that are performed. Understanding and making information from this data can be quite difficult. All data should be thoroughly reviewed before filing away test reports.

On site oil testing: In-shop, in-house, and bench-top are all terms associated with on-site oil analysis. Mini-lab oil analysis is most often accomplished by condition based maintenance personnel in conjunction with their vibration analysis duties. Several thousand plant maintenance departments have decided to perform at least a portion of their oil analysis on site. The amount of lab analysis depends on capabilities of the mini-lab.

Here are some of the reasons to perform on-site oil analysis:

- Ownership and control of the analysis.
- Immediate results.
- Immediate retest when needed.
- Analysis is done by the people who know the most about these machines.
- Electronic data with no transfer.
- More frequent testing.
- Test lubricants before using.

The on-site mini-lab that performs industrial oil analysis should have the following:

- Quantitative WDA (e.g., Ferrous Density).
- Qualitative WDA (e.g., Analytical Ferrography or Analytical WDA).
- Particle counting.
- Water measurement such as crackle or time-resolved dielectric.
- Oil chemistry measurement such as dielectric or voltametric or TAN/TBN test kits.
- 40 C viscosity.
- Expert system in software.
- Electronic import and export to and from labs.

CBM Programme Assessment: The core technology of oil and grease analysis is used to varying degrees at most nuclear power sites. The CBM self assessment programme provides guidelines for determining the effectiveness that the technologies are being employed and identifies opportunities for improvement. Additional CBM technologies that are used within the CBM programme, that are used by other groups within the plant, or that are not used but are expected to be cost effective, are included unless specifically excluded from the assessment.

Oil and grease analysis

- Condition data from oil analysis can be used to monitor not only the quality of the lubricating oil but to make judgments regarding the condition of equipment. New oil reference samples are used for comparison and alert/alarm level determination and adjustment [37].
- Lubricating oil is changed only when analysis shows degradation of lubricant properties or accumulated wear particles (normal wear).
- Oil analysis sample taps are utilized to increase programme consistency, repeatability of samples, and lower labor costs [38].
- Sample locations are selected based on system design.
- Analysis results from labs are transmitted to the customer in 24–48 hours. The results are electronically mailed to the site with trending data through the use of common software supplied by the laboratory.
- The analysis testing package is tailored to the type of equipment being monitored, including items such as large particle analysis, where applicable.
- Oil filtering equipment is used, where applicable, to further increase oil change intervals.
- The manufacturer nominally ± 10% determines viscosity limits [39].
- Baseline comparison levels are determined by new oil sample analysis.
- Large particle wear analysis is used to monitor equipment condition.
- Alarm and alert levels are established using ISO and ANSI standards as a basis.

Benefits

By undertaking condition based maintenance further benefits may be expected as a result of the effective execution of the programme [40].

1. Direct Benefits

Improve plant safety: Condition based maintenance programmes ensure that the ‘correct’ type of maintenance is undertaken at the optimum interval and on components that have safety significance.

Improved component/system reliability: A condition based maintenance programme ensures that the correct maintenance is undertaken. This will lead to a reduction in down time and post maintenance defects. The use of on-line monitoring, performance monitoring, improved maintenance techniques, complemented by improved training and competencies will contribute to a reduction in component failures.

Cost management: The effective implementation of a condition based maintenance programme can deliver resource savings. To ensure maintenance programmes are optimized, it is necessary to implement a continuous review of the maintenance programme such that the measures are checked regularly and the appropriate maintenance techniques are applied within the life cycle. By reviewing all existing maintenance activities the techniques used will establish the base costs of undertaking maintenance tasks, establishing the cost of activities (activity based costing), this can be used as a more accurate indicator for maintenance optimization.

Save time/do more: Reducing the maintenance on components that are lower graded and replacing resource intensive activities with more appropriate maintenance techniques. This will release resource to undertake more significant components maintenance.

Improved planning and scheduling: The condition based maintenance catalogue will assign an accurate activity priority, making work scheduling more effective.

Less waste – environmental management: The volume of the maintenance tasks requiring consumable items and creating radioactive waste can be reduced, thus resulting in an overall year on year reduction of contaminated waste. This can also apply to non-contaminated waste. There can be a year on year saving on consumable such as non re-usable lagging materials.

Reduce collective dose: The elimination of low priority maintenance tasks and more appropriate maintenance techniques will result in a reduction in the collective dose.
Increased unit energy availability: The condition based maintenance process can reduce the high risk of scram or reduced output. This may never be eliminated, but there will be increased justification for undertaking such activities.

Reduction in emergent work: The condition based maintenance process will reduce emergent work through application of the most appropriate maintenance technique.

Improved justification: The condition based maintenance process uses techniques to establish the type of maintenance and the safety significance of the plant component. This coupled with the costing information, enables a clearer justification to be made as to why the management decisions are made on a day to day basis.

2. Indirect Benefits

Improved maintenance culture: Condition based maintenance will generate a greater level of staff involvement in core decision-making and will result in ownership of the process being transferred to a lower level.

Communication and awareness: The condition based maintenance process is a very powerful vehicle for change. It therefore increases staff awareness of the business need to optimize processes and brings with it a sense of business awareness and familiarization of the maintenance techniques.

Limitations of Tribology

Three major limitations are associated with using tribology analysis in a condition based maintenance program: equipment costs, acquiring accurate oil samples, and interpretation of data [41].

Capital Cost: The capital cost of spectrographic analysis instrumentation is normally too high to justify in-plant testing. Typical cost for a microprocessor-based spectrographic system is between $30,000 and $60,000. Because of this, most predictive maintenance programs rely on third-party analysis of oil samples.

Recurring Cost: In addition to the labor cost associated with regular gathering of oil and grease samples, simple lubricating oil analysis by a testing laboratory will range from about $20 to $50 per sample. Standard analysis will normally include viscosity, flash point, total insoluble's, total acid number (TAN), total base number (TBN), fuel content, and water content. More detailed analysis, using spectrographic, ferrographic, or wear particle techniques that include metal scans, particle distribution (size), and other data can cost more than $150 per sample.

Accurate Samples: A more severe limiting factor with any method of oil analysis is acquiring accurate samples of the true lubricating oil inventory in a machine. Sampling is not a matter of opening a port somewhere in the oil line and catching a pint sample. Extreme care must be taken to acquire samples that truly represent the lubricant that will pass through the machine's bearings. Proper methods and frequency of sampling lubricating oil are critical to all condition based maintenance techniques that use lubricant samples. Sample points that are consistent with the objective of detecting large particles should be chosen. For most industrial equipment in continuous service, however, monthly sampling is adequate. The exception to monthly sampling is machines with extreme loads. In this instance, weekly sampling is recommended.

Understanding Results: Understanding the meaning of analysis results is perhaps the most serious limiting factor. Results are usually expressed in terms that are totally alien to plant engineers or technicians. Therefore, it is difficult for them to understand the true meaning, in terms of oil or machine condition. A good background in quantitative and qualitative chemistry is beneficial. At a minimum, plant staff will require training in basic chemistry and specific instruction on interpreting tribology results.

IV. FAILURE MODE ANALYSES OF NPP

There are concerns that a combination of human and mechanical error at a nuclear facility could result in significant harm to people and the environment [42]. Operating nuclear reactors contain large amounts of radioactive fission products which, if dispersed, can pose a direct radiation hazard, contaminate soil and vegetation, and be ingested by humans and animals. Human exposure at high enough levels can cause both short-term illness and death and longer-term death by cancer and other diseases [43]. It is impossible for a commercial nuclear reactor to explode like a nuclear bomb since the fuel is never sufficiently enriched for this to occur [44]. Nuclear reactors can fail in a variety of ways. The instability of the nuclear material generates unexpected behaviour, resulting in an uncontrolled power excursion. Normally, the cooling system in a reactor is designed to be able to handle the excess heat this causes; however, the reactor also experiences a loss-of-coolant accident degrading the fuel or causing the vessel containing it to overheat and melt. This event is called a nuclear meltdown. After shutting down, for some time the reactor still needs external energy to power its cooling systems. Normally this energy is provided by the power grid to which that plant is connected, or by emergency diesel generators. Failure to provide power for the cooling systems, as happened in Fukushima, can cause serious accidents. Intentional cause of such failures may be the result of terrorism. The failure analyses comprises of study performed on disturbed entity / unit in a sophisticated way revealing the factors or variables affecting them. Such system of prime importance needs careful assessment of all the modes of that failure. The analyses can be done qualitative (FMEA) & quantitative (FMECA). Failure Mode & effect analysis is a systematic analysis of potential failure modes using qualitative approach aimed at preventing failures by conducting reliability analysis. Failure mode & effect criticality analyses uses quantitative approach for determining criticality and probability of occurrence of each failure modes now these analysis are intended to be implemented during the design phase to have maximum influence & positive output. This includes the identification of causes of failure & its effects on the operational capabilities of system & process. A nuclear power plant, therefore need to focus on both the Qualitative & quantitative failure modes & there effects on their system by ranking category & criticality of failure modes. The failure modes give an indication about the way the system unit may fail with respect to operating conditions. Various authors have tried to rearrange the failure modes [45] from seismic viewpoint of nuclear power plant buildings, equipment, vessels and piping. The mechanisms of failure in case of earth quake / natural calamity as follows: (i) damaged by the dynamic effect of acceleration waves, (ii) by resonance in displacement waves, (iii) by the static effect of seismic force, (iv) by external force from attached piping and others, or forced deformation, and (v) by liquefaction of soil. The authors have also shown the modes of failure of the following items in a aseismic design matrix form of the mechanisms: (i) the reactor building, (ii) steel containment vessel, (iii) auxiliary building, (iv) reactor vessel, (v) core internals, (vi) primary and secondary coolant system, (vii) emergency power supply system, (viii) emergency gas treatment system and stack, (ix) fuel cooling pond and fuel rack, (x) refuel machine crane, (xi) auxiliary system and component, (xii) turbine and its pedestal, and (xiii) main power system and control instrumentation.

CONCLUSIONS

A nuclear power plant is an entity/ system of prime importance to a nation, subjected to severe operational risks. Some level of scheduled, preventative type maintenance will always play a role in valve performance and reliability. However, diagnostic and condition based decision making ensures that the correct type and amount of maintenance attention is applied to components that need maintenance thereby reducing the cost and schedule impact of unnecessarily maintaining good equipment.

The CBM programmes depend upon the ability of the staff to assimilate the information into usable trends and combine seemingly unrelated technology outputs into sensible story boards that help to define how the equipment is performing. Within the subtleties, will be those infrequent findings that make the process worthwhile by preventing generation losses and helping to plan for controlled overhauls of critical equipment.

The CBM staff faces many challenges within the technologies. Their management must also face the task of developing their next generation of reviewers who will need the knowledge of time and experience to carry on the current team's activities. Condition based maintenance (CBM) assumes that all equipment will deteriorate and partial or complete loss of function will occur. CBM monitors the condition or performance of plant equipment through various technologies. The data is obtained, analyzed, trended, and used to predict equipment failures. When equipment failure timing is known, then actions can occur to prevent or delay failure. In this way, the reliability of the equipment can remain high. Condition based maintenance uses various sensors (e.g., pressure, temperature, vibration, flow) and fluid (e.g., oil and air) samples. With these sensors and samples, condition based maintenance obtains indications of system and equipment health, performance, integrity (strength) and provides information for scheduling timely correction action. In this paper we have discussed the development of condition based maintenance of NPP. It is part of the spectrum of NPP inspection and recording activities to do with plant life management and is a 'growth area' which could encompass and include some of the existing inspection and record keeping activities. This subject continues to be developed. This paper described the steps, using a tribology technology, for building an optimized & effective condition based maintenance. This will reduce the risk associated with the nuclear power plant, Furthermore it blends in economic factors in order to provide an automated system for making optimal decisions given an asset's current working age and its latest monitored condition data. The optimization objective may be set in the model as lowest overall cost, highest average asset availability, or adherence to a minimal risk criterion or to a stated policy declaring a desired ratio of preventive to failure maintenance.

ACKNOWLEDGEMENT

We are thankful to Department of Mechanical Engineering of MANIT Bhopal India for providing the required facilities needed for the successful completion of this paper.

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