INFLUENCE OF DESIGN IMPROVEMENTS IN OPTIMISING STAFFING OF NPPs — AN INDIAN EXPERIENCE

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Abstract

Three decades of operating experience in India has led to sustained high performance of NPP's. The staffing modules and policies are standardised. The basic functions of operation, maintenance, technical support and quality assurance are carried out by a team of 727 in-plant persons (for a 2 × 220 MW PHWR station) organised at five levels, for fifty positions in ten job families. The organisational factors that led to optimising of staff are described in the companion paper. This optimisation of manpower is a result of continuous learning — for (i) optimising quantum of workload and (ii) improving productivity. For the first category, design improvements over older Indian NPP's have increased reliability, operability, maintainability and human factors. Few examples: (i) improved man–machine interface in plant controls and on-power refuelling system with operator guidance, logging as well as diagnostic/health monitoring features; (ii) spread out layout for better access and ease of maintenance, separation of plant services for unit-1 from unit-2 and, removal of reactor auxiliaries out to separate buildings; (iii) reduction of maintenance tasks through redesigned equipment and improved condition monitoring means. However, design and procedural improvements also include additional equipment for upgradation of safety measures e.g. larger number of safety related pumps separate switchyard control room and increased service system equipment. This paper outlines experience of design improvements in optimising staffing and uses a specific case illustration to establish the findings for better use of staff.

1. INTRODUCTION

Assessment and optimisation of staffing is basically an assessment and optimisation of workload against certain expected productivity. The workload are derived from the design and human activities — both planned as well as unplanned in the NPP productivity of NPP personnel is a key contributor towards optimising staffing and design needs to keep in view the risk of human error for various activities. Productivity is also influenced by the environmental constraints such as ALARA needs, layout, accessibility and ease of working. Design contributes greatly towards improvement of workstation.

Optimisation of workload can be made possible at source level by suitable design and operation measures to minimise failures and outages which create unplanned work. However, such measures do create certain additional programmes of surveillance, monitoring, training and quality assurance to create additional planned workloads. Design improvements, therefore, seek to create net reduction of unplanned workloads while supporting productivity improvements.

2. TYPICAL DESIGN IMPROVEMENTS TO IMPROVE PRODUCTIVITY

2.1. Improved man–machine interface and automation

2.1.1. Reduced workload

The increased level of automation reduced response time and quality of decision making of operation staff, e.g.

(i) Transients handling needed 15 to 20 alarm handling within 2 to 5 seconds in older NPP. Computers now indicate "the first out" alarm, greatly facilitating diagnosing the fault. This even saves "poison-outs". Outage reduction directly reduces workloads and staffing requirements;

(ii) Computerised reactor protection system such as Programmable Digital Comparator System eliminates electromechanical relays and alarm indicators with password controlled setting changes. This also reduced spurious trips substantially. Similarly control room computer system (data acquisition system) has substantially reduced strip chart recorders, analog-meters and relay annunciators, reducing operations as well as maintenance workload;

(iii) The operators are able to successfully and productively interact with the computer system on its structured inputs and outputs, its prompts, diagnostic messages and help menu and are thus more productive. For example, detection of and exact locations of occurrences e.g. of fire, D2 0 spillage have been made easy and less time consuming.

2.1.2. Cultural factors

The success of computerisation in improving productivity however had been dependent on certain attitude factors e.g.:

— if sensors picked up noise and caused chattering, the computer should not be blamed by operators;
— maintaining logs only on computers as a culture and not on papers also as options;
— not looking for extra staff for keying in log information.

2.2. "ALARA" by design changes

Minimising individual and station doses to implement ALARA have been one of the important design goals. The examples of measures adopted in design of NPPs are given below. All such measures are also effective in reducing outages, breakdowns and therefore reduced man-hours of maintenance.

2.2.1. Selection of materials

At NAPS /KAPS and 500 MW(e) units, mushroom type steam generators have Incalloy-800 tubes with less percentage of nickel. This has substantially lowered radiation field due to cobalt-60. Also the reactor vault is water filled with no air present and this eliminated Argon-41 activity.

2.2.2. Separating radioactive areas and spread out layouts

Nuclear auxiliaries such as auxiliary cooling purification systems and D_2O recovery dryers have been located in a specially ventilated separate building away from main reactor coolant and moderator system. This enables optimisation of space around reactors too. Also at RAPS/MAPS, emphasis on compactness to reduce heavy water hold up had resulted in a moderator room where there is hardly any space left for maintenance. With deletion of equipment for moderator dumping system for reactor trip, further space is available e.g. for in service inspection of moderator heat exchangers.

2.2.3. *Minimising leak*

The D_2O systems contain tritium and gamma activity. To minimise spread of activity some of the design measures taken in the moderator system from NAPS onwards are (including 500 MW(e) units):

- reduction of number of flanged joints from about 170 per unit (at RAPS) to about 34;
- use of flanged butterfly valves at RAPS is replaced by welded gate valves for better isolation and diaphragm valves by bellow sealed valves;
- reduction of number of valves, from about 200 per unit (at RAPS) to about 100.

2.3. Design demanding additional workload (new NPP's)

Enhanced safety requirements have brought in following design changes in the newer NPP's under construction e.g. at Kaiga and RAPP-3&4.

- Additional safety related pumphouses and firewater pumps and additional (unitised) fuel loading and transport equipment. Additional operational and maintenance surveillance are called for;
- Separate buildings for the two turbine halls, separate diesel generator building, separation between unit-I control panels from unit-2 panels in main control room, separate (electrical) switchyard control building. These will increase walking distances and call for additional manning points for operators. To illustrate, in case of transients such as line tripping or power failure, all alarms, relay flags, communications with grid authorities and operations of 220 KV controls will have to be done in the switchyard control room — remote from control room.

2.4. Remarks

The next section provides in a case study on on-power refuelling system design improvements for optimising staffing.

3. CASE STUDY: EXPERIENCE WITH FUEL HANDLING SYSTEM STAFFING

3.1. Background

3.1.1. *General*

Fuel handling system does on-power refuelling and handles radioactive spent fuel from the reactor for safe transfer to the storage bay. All operations are to be done remotely and safely as the equipment are located in inaccessible areas. The fuelling machines home-on to the reactor channels, remove plugs, load fresh fuel at upstream end and receive spent fuel into the fuelling machine at downstream end. The fuelling machine is then moved to fuel transfer system for exchange of spent fuel for fresh fuel and transfer system to the spent fuel storage bay. The sequential operation logic of the machines is organised into **sequences** comprising of a number of **programs** executed **stepwise**. Each step consists of a logical combination of permissive which permit execution of a set of commands. The step is done, when the feedbacks indicate a successful execution of the commands. The basic goal or challenge lies in completing the channel operation in minimum time without compromising safety and quality.

3.1.2. Problems and issues

In the early eighties, at RAPS / MAPS, the fuel handling operators had a tough job. They relied more on their observation on the operators console and recorder charts for analysing causes of equipment failure and events and corrective actions. For example, whenever there were problems in removal of the plugs, the operator intervened manually through operator console, for executing all sequential steps. There were chances of diagnostic delays and errors. There were at times, over 70% downtime of the machine with only particular components failing repeatedly. Absence of systematic training in fuel handling discipline at that time, difficulties in planning preventive maintenance as well as non- availability of custom-built spares became serious bottlenecks. The only way to meet refuelling needs was to increase both operation and maintenance staff strengths and do two-shift operations for refuelling.

3.1.3. Staffing increases

At RAPS in eighties the repetitive, sequential and strenuous panel operations coupled with frequent problems with field devices led to large amount of manual operations and continuous supervision. A typical crew then would comprise of

— One fuelling engineer (per crew);
— One control panel operation (per unit per crew);
— Two assistant operators;
— One area operator for spent fuel bay.

Two crews did fuelling

For two units and three crews therefore, the fuelling staff comprised of

3 Engineers
6 Control panel operators
12 Assistant operators
6 Area operators

Total = 27

Refuelling group is an autonomous group with its own operation, planning, analysis and maintenance group. For planning and technical support another 10 persons were needed bringing the total to 37 operations. However, in the early stage, the fuelling machine component failure rates were extremely high giving a down time of about 50%. So the staff was divided equally between operation and maintenance giving a total of 37+38 = 75 for refuelling crew. This was later raised to 93 to meet the requirements of continuous unit operation.

3.1.4. Initial experience at NAPS on new system

Subsequently systematic training programs were introduced at all NPP's for fuel handling personnel. However, introduction of a new computerised system at NAPS with redesigned fuel transfer system created some teething troubles during commissioning e.g., to readjust various cards (on gains, non-linearity etc.), modify software (in e.g. accuracy check bands, delays on device operations) as also testing on integrated system. This new system demanded additional commissioning staffing for various readjustments including fuel transfer systems.

3.1.5. Design and systematic changes later

Subsequently, at NAPS, KAPS, the fuelling performance improved. The refuelling time came down to just under 2 1/2 hours, with the system operating on auto 80% of the time and maintenance time taking only 15%. What is equally significant is that we could bring down and standardise staffing levels also for KAPS. At RAPS / MAPS also, design improvements on site (e.g. relocating leak detector valves away from inaccessible, high gamma area under the snout in the fuelling machine head reduced maintenance time), systematic maintenance planning (e.g. replacing periodically the ball valve seals drastically brought down seal failures in fuel transfer room) and formal training and certification of fuel handling staff improved the performance substantially at all levels.

The next section outlines specific examples of design improvements in NAPS onwards.

4. SPECIFIC IMPROVEMENTS — OPERATIONS

The new design of man–machine interface computer controls and process design at NAPS / KAPS have substantially reduced operator workload at the same time improved their productivity and supports. Some examples:

4.1. Man–machine interface

4.1.1 Automated device positioning

Auto positioning needs very skillful manual operations e.g. for positioning the fuelling machine carriage on the required reactor channel. In the computerised fuel handling system at NAPS / KAPS, this positioning is done by the micro-computers. The operator selects the channel location; the program number and program logic, the fuel bundle and rest are done automatically. They also read digital panel meters which do not strain eyes for monitoring long travels on dial type meters.

4.1.2. Automated error /mismatch detection

For refuelling, the operator must have full status information. At RAPS / MAPS, if e.g. a reference potentiometer slipped, the fuelling machine could home on to wrong channel and this could be known only when second pair of bundles were being pushed. Considerable man-hours could get lost. At NAPS / KAPS, this matching is done by the computer.

4.1.3. Guided problem solving

The reason for any "HOLD" appears on the display, thus avoiding diagnostic errors. Even if the operator decides to bypass a certain interlock, there is no need to "jumper" and with a risk to forget to remove the jumper later. He now only presses "skip" button for every bypass. Operators therefore now concentrate more on monitoring, rather than diagnosing, checking and manual logging.

4.2. Reduced cycle time due to process design

At RAPS/MAPS, at one time, only two spent fuels can be discharged to fuel transfer port. Also at that time, new fuel loading cannot be done. In subsequent designs, all eight bundles can be discharged at one time in just half the time, simultaneously new fuel can also be loaded in the fuelling machine head. Also NAPS has separate spent fuel receiving stations for each reactor. So, simultaneous transfer of spent fuel to bay for storage from both reactors is possible.

5. IMPROVEMENTS IN MECHANICAL MAINTENANCE ACTIVITIES

The following examples illustrate measures that reduce maintenance workload and maintenance time.

5.1. Human engineered design

Examples are:

(i) Installation of the Ram assembly was very difficult at RAPS / MAPS / NAPS, as its one part "ball screw" was assembled in ram housing, while its mating ball nut was placed in magazine housing. The points here are two i) any mismatch in alignment here could jam the ball screw assembly and ii) during disassembly for doing maintenance it would take considerable time to take out ball nut from magazine thus increasing maintenance time. At KAPS the redesigned ram housing houses the ball nut also and makes assembly / disassembly much simpler; further more, the ram assembly has been relocated at a convenient working height which improved quality of maintenance;

(ii) In the fuel transfer system, transfer magazine and shuttle transfer tube are physically separated by having two valves with a gap to avoid accidental mixing of D_2O with H_2O.

5.2. Towards simplification and ALARA

Some examples are:

(i) At RAPS/MAPS, the fuelling machine service area is separated by a complex door (carriage access door). At NAPS, therefore the service area is provided underneath fuelling machine vault totally isolated from other accessible areas to facilitate maintenance and adjustments. The design is considerably simplified with much reduced number of components in e.g. cable carts, carriage, etc.;

(ii) A special service cart is provided to lift and lower the fuelling machine head for assembly and disassembly;

(iii) Supported fuelling machine columns and bridge structures are less complicated, easier to manufacture (and therefore to maintain) and do not demand high accuracies as in the older NPP's;

(iv) Oil hydraulic panel and power units are located in accessible areas to facilitate adjustments, maintenance and trouble shooting;

(v) The number of equipment new fuel passes through before reaching the fuelling machine and the number of times the bundle negotiates the ball valve have been substantially reduced almost to half of those in older NPP's.

6. IMPROVEMENTS IN CONTROL SYSTEM MAINTENANCE

The reduced hardware, more reliable hardware and computerised maintenance aids have improved productivity, reduced workloads and maintenance time. Some examples:

6.1. Maintenance free hardware

Since computers do most positioning of devices, there is a substantial reduction in conventional relays type hardware, limited to only few manual logic cards for emergency operations. Use of standard logic gates with much higher packing density further reduced hardware while improving reliability. Also there are just nine LVDT's (linear variable differential transformers for sensing positions) and this reduced considerable calibration workload. Use of single-turn potentiometers for Ram-C both coarse and fine, saved considerable downtime due to over-travel of the wiper shaft of multi turn potentiometer when the tape broke, in older NPP's.

6.2. Guided trouble shooting

The position of any field potentiometer can be checked right on operator console — there is no need to go to field for maintenance checks. Similarly one can verify the calibrations against tables stored in the computer.

6.3. Prompt diagnosis

Maintenance off line tests also check if pressing of switches is leading to intended operations. There is no need to take electrical drawings and measure logic levels, unless there are faults. Status of the control system including any system failure is directly indicated.

6.4. Reduced overall configuration

The system at RAPS / MAPS had voluminous wiring, huge floor mounted power supplies and logic racks. There were more maintenance attentions needed obviously due to higher heat dissipation, higher noise pick-up and distances involved. The compact system at NAPS onwards have thus enabled control maintenance staff towards more planned activities. Bringing out input / output connections on the front connectors of the logic boards and extending their connections to the interface modules greatly reduced back-panel wiring and noise pickup at NAPS. Use of switched mode cabinet mounted power supplies caused much less heat dissipation problems.

7. IMPROVED SUPPORTS

Given below are few examples of improved supports by design efforts in the new NPP's.

7.1. Health monitoring aids

The computerised logging now provides report on e.g.:

(i) how much time each execution step took including causes of any delays permissives not available and;

(ii) deterioration in performance of ram assemblies by correlating with their auto-positioning time. This has enabled systematic preventive and predictive maintenance.

7.2. Operator error logging

Analysis of computerised logging of operator errors now provides an objective basis for systematic monitoring of on the job training.

7.3. Operations training simulator

At Kaiga a replica fuel handling training simulator is being installed. The facility will provide training on operations under all modes, failure conditions and error likely situations.

7.4. Calibration and test facility

In the upcoming 500 MW(e) NPP's, a light water facility is being provided for testing serviced subassemblies such as ram assemblies and components like oil hydraulic valves. Located in tritium-free area, the facility will provide for all fuelling machine head operations as in a reactor. It will reduce downtimes and radiation doses as well as continuously impart maintenance training to fuel handling personnel.

8. IN SUMMARY — BETTER USE OF STAFF

On power refuelling as just one typical example of NPP operation, employs complex technology and demands very competent operation and maintenance. The experience feedback to design and operation led to improved reliability, operability, maintainability and also support towards higher productivity. These efforts have reduced workloads despite upgradation of performance requirements and also improved productivity of people. As a result staffing level has been optimised and brought down while maintaining high performance. This was a case study to bring out role of design in optimising staffing and making more gainful, enjoyable work life of operation & maintenance personnel in the entire NPP.