LEARNING FROM THE BEST WITH PROCESS BENCHMARKING IN NUCLEAR POWER PLANTS

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ABSTRACT

Process benchmarking between power plants of different utilities has been a tedious task due to the difficulty to obtain significant and suitable data. Only independent consulting agencies with unrestricted access to sensitive operational data gained through projects in various comparable power plants can perform such a task. In order to conduct a holistic, integral benchmark analysis, the basis of such an analysis - the measurement data and key performance indicators - need to be determined. In a second step the verified data needs to be standardized to ensure comparability before the organizational structure and technical processes can be adjusted to the best-practice.

Determining real process data

In the process of such evaluation, it is imperative only to use data that is comparable. Process data can only be compared, if the data itself is assessed as exactly as possible. The most precise method of determining process data nowadays is through process data reconciliation – the calculation of the most likely values introducing uncertainties and closing all mass-, energy- and material balances fulfilling all interdependencies in a covariance matrix of the entire plant process. This reconciled data is calculated on a continuous basis and can be compared to the data of other plants. Non-measurable key performance indicators such as single-component and overall efficiency rates can be calculated in a reliable and exact manner.

Comparing real data to other plants

A plants’ processes are investigated according to their impact on plant availability, plant safety, maintenance costs and operation costs. In order to ensure comparability throughout the benchmark analysis, processes data has to be adjusted for the plant type, plant supplier, plant age, site specific factors and local legislation. If plant availability and safety are on a comparable high industry level, “cost-driver” processes will be identified and analysed regarding their technical and financial feasibility.

Adjusting process to best-practice plant process

Earlier projects will have generated “optimal” plant processes of a virtual benchmark plant. This virtual plant is updated continuously in order to incorporate all new findings with regards to best-practice technical and financial properties of a plants’ processes. Best-practice processes from the virtual benchmark plant need to be incorporated into the existing organizational structure and technical documentation of the analysed plant. All processes, existing and best-practice, are evaluated both financially and technically before and after adjustment to the best-practice processes. This leads to a precise cost-benefit analysis beforehand and a verification of results after completion of the benchmark analysis.
INTRODUCTION

Problems of current benchmarking methods

Process benchmarking among nuclear power plants (NPP) of different utilities has been a tedious task due to the difficulty of obtaining significant and suitable plant process data. Plant operators do not readily make available detailed process or performance data for other plants due to competition or security reasons.

Benchmark studies in the past have worked with acceptance test data from power plant suppliers, whereas the current plant status was derived from an assumed ageing curve and applied to the various systems and components. These analyses are mostly limited to general information about the plants’ condition and their standing compared to reference plants. General information includes:

- yearly production
- outages
- turbine manufacturer, type and year
- plant size
- steam pressure and temperature
- mean coolant temperature
- supplier and manufacturer of plant, systems and components

With the help of the before mentioned data, external consultants have tried to derive certain benchmark key performance indicators (KPI) using assumptions such as natural degradation of components as well as operational and external effects. Usually these KPI represent overall, system and component operational rates of efficiency /1/.

This method of benchmarking runs the risk of error propagation, since it derives its results from data based on assumptions. Furthermore, comparing nuclear power plants with KPI on efficiency rates is a useful but very undifferentiated approach.

For example, there are hardly any known benchmark analyses that focus on the link between actual labor cost and full costs of processes and activities. This results in single maintenance activities - major cost drivers in NPP - not being measured financially not as processes or activities but rather as unspecified parts of a bigger, intransparent whole.

Currently, NPP staff has two possibilities to compare process or plant performance:

Through
- Industry conferences
- Industry publications or organisations
- Peer visits on-site or personal contacts

However, these benchmark approaches don’t offer a solution to the problem of information being withheld for competitive reasons or due to safety regulations.

A new, independent, more detailed and at the same time more integral method should be employed to better reflect technical and economical issues in NPP processes.

Approach to a solution

When operating and managing power plants, there are three general postulates that have to be satisfied.

- Maximum safety
- Maximum production
- Maximum cost efficiency

All three postulates are interdependent on factors such as single component and overall efficiency rates, plant down time, maintenance activities, and regulations, as shown in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Plant efficiency</th>
<th>Down time</th>
<th>Maintenance activities</th>
<th>Regulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Cost efficiency</td>
<td>0</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Production</td>
<td>0</td>
<td>-</td>
<td>+</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1: Controllable influencing factors of a plant’s objective function

Influencing factors are interdependent. Measures used for the fulfillment of one postulate can yield changes in others. The objective function therefore is the maximizing of performance area (P). The reciprocity of the postulates differs from plant to plant and needs to be adjusted for each case having evaluated past events and their impacts on safety, production and cost efficiency.

Max P(x) = f ( SafeMax, ProdMax, EffMax )

The weighting of the postulates can differ depending on world energy prices, general political conditions, environmental regulations, labor and material costs. However, the goal is to maximize performance area P at all times, as shown in Figure 1.

Figure 1: Performance area P
This paper focuses on the economic aspects of technical processes such as maintenance activities and process efficiency. In order to maximize P, various tools can be utilized to achieve the maximum level of the respective postulate. These are

- Condition-based maintenance
- Risk-based maintenance
- Quick and continuous detection of process inefficiencies with process data reconciliation (PDR) and post-processing
- Minimizing the number of maintenance activities through benchmark analysis

Condition based maintenance can be introduced to replace recurring maintenance activities where tools such as vibration measurement can be applied. Risk-based maintenance is a theory of optimizing the number of maintenance activities by evaluating and statistically quantifying the likelihood of certain events occurring. Process data reconciliation takes into consideration uncertainties for all measurements throughout the process, transforming all measurements into an interdependent correlation matrix, continuously closing mass-, energy-, and material balances /2/.

The method described in detail in this paper, compares various plants’ maintenance activities and performs a benchmark analysis, based on the assumption that, given that safety standards of both plants are the same and production levels are comparable, maintenance activities with the lowest full cost are best-practice.

MEETING THE POSTULATES

Maximum safety: Adhering to or exceeding the current level of safety

Safety in NPP inherently depends on plant design, manufacturer, responsibility of operating personnel, training, organizational competence, and, to a high degree, maintenance activities. More stringent regulations – including more recurring, preventive maintenance activities mostly yield a higher degree of safety. This increased safety due to the increased number of maintenance activities is negatively correlated to cost efficiency.

The level of safety, being a non-negotiable factor in plant operation but at the same time a major cost contributor, needs to be adhered to if not exceeded while minimizing costs by introducing new technologies and methods, such as PDR and benchmark analysis.

Maximum cost efficiency: Inductive and deductive approach to full costs

Of special interest to a plants’ management are cost optimising measures. When analysing a plant’s cost structure, maintenance costs, including

- Incident and defect notifications
- Recurring testing and activities

represent a major cost contributor in the effort to maximize the plant’s performance. Not only is it important to consider the directly allocatable (variable) costs such as labor time and material but also all administrative costs (fixed). These costs combined represent the full cost of maintenance.

In a first step, the so-called cost-drivers need to be identified, i.e. systems with combined costs exceeding 50% of overall maintenance costs (material and contractors). In order to perform an integral analysis on a full cost basis, a two-way approach needs to be adopted, calculating the average cost for each maintenance activities:

- divisional level - total cost on labor, material and administration divided by number of maintenance activities
- process level - after detailed activities of each process step are measured financially and summed up to yield the actual full cost of an activity, the average over the activities is calculated

Independent institutions with unrestricted access to detailed technical and financial plant data such as consultancies, are able to gather data from different plants in a plant database and make the data comparable.

Maximum production: Knowledge of process parameters in client NPP

Data about outages, planned or unplanned, yearly total production and hour of operation is, generally spoken, common knowledge. Each day or week that a plant is standing still in an outage equals Millions in lost profits. It is therefore imperative to maximize plant production. There are different tools that can be used for achieving maximum production. In case of

1. Unplanned outages

A Plant tripped due to leakages, wrong measurements, exceeding limits, etc. (process changes or measurement faults)

Process measurements need to be reconciled with the help of process data reconciliation (PDR), and real process parameters need to be monitored continuously. Process optimizations and maintenance activities need to be based on and initiated by findings in the post-processing of reconciled data (process inefficiencies, measurement drifts, process changes). PDR substantially helps reducing numbers and length of unplanned outages by indicating process inefficiencies before an outage and minimizing the time to pinpointing the cause of an outage.

B Unexpected prolongations of planned outages due to wrong planning, wrong material, erroneous reassembly or wrong maintenance

Software planning tools, sound project management, knowledge of current technologies and best practice in the industry help to reduce the time in outage and avoid unnecessary activities that might prolong a planned outage.
2. Planned outages

Plant is shut down for a yearly (or bi-annual) planned outage. The dates are usually set in seasons with low wholesale prices in spring or fall.

3. Maximum output

In order to run plants above their designed output rate of 100%, various tools to uprate a plants’ output are available in the market. Operators can either try to singularly enhance measurement values by exchanging existing devices with new generation meters (such as UFM) or use PDR to interdependently and integrally minimize process uncertainty over the whole process. Both instruments are accepted to perform system uprates of 1.4% to 101.4%.

Configuration of virtual best-practice NPP

Each benchmark defined for the plant (cost efficiency/production/safety) needs to be quantified by indicators:

- **Cost Efficiency**: negatively correlated to amount of maintenance activities
- **Production**: needs to be based on PDR determined plant efficiency (which will serve as the general key performance indicator (KPI) and is negatively correlated to plant down-times
- **Safety**: negatively correlated to reportable incidents in the plant

All available information on processes from various NPP needs to be gathered in a single database.

- Maintenance activities including plant identification number, description of work done, labor hours, material used, reason for maintenance (recurring, condition based, etc.)
- Detailed key performance indicators of operations need to be calculated based on reconciled (“true”) data, such as system efficiency rate, component efficiency rate, etc.
- Detailed technical information on process parameters such as mean coolant temperature, thermal reactor power, etc.
- Outage times, types of shut downs (forced/ planned), descriptions
- Reportable incidents, levels, descriptions

Standardization of database information

In order to fit the database information on performance, maintenance, technical parameters and indicators on outages and safety to various types and ages of NPP, data has to be standardized according to

- plant type (BWR, PWR)
- number of redundancies (e.g. diesel generators)
- organizational structure
- plant/ component supplier
- plant age
- site specific factors
- local legislation
- exceptional one-off maintenance activities (projects)

The standardization is usually expressed in adjusted maintenance cycles, maintenance activities and cost adjustments due to differences in levels of either production or safety. The methodology in standardization cannot be generalized, it needs to be differentiated on a case-by-case basis.

Determining the best-practice plant processes and the virtual benchmark plant

After the plant specific data is standardized, it needs to be compared to other plants in the database and the best process practice of each field (type of maintenance activity, maintenance interval, merging of different activities, materials used, etc.) is determined and designated as the benchmark.

Best practice processes are taken from each plant and implemented in a virtual best practice plant. Processes are chosen based on

- material cost
- labor cost
- technical feasibility
- effects on availability
- effects on safety

Best system and component KPI (efficiency rate etc.) are taken from single plants and used as benchmarks for the virtual best practice plants.

Adjusting real processes to virtual best-practice plant processes

Standardized best-practice processes are chosen from the virtual benchmark plant and implemented into the clients plant after translating the standardization into the plant’s specific characteristics. In addition, approval from the Regulatory Commission needs to be obtained. The arguments for such an approval will be based on the comparability with the benchmark plants and their respective, already existing approval. In a second step, management and staff need to be integrated in the process in order to support the changes in cost efficiency and technical feasibility. The implementation of the new best-practice processes will implicate changes in:

- organizational structure
- documentation such as work instructions, manuals
- maintenance planning

After the clients plant has been adapted to the best-practice processes of the virtual benchmark plant, the changes have to be measured. In order to measure changes, indicators have to be agreed to:

- maintenance cost in plant (labor/ material) before and after analysis
- total down-time before and after (adjusted to exceptional events/incidents)
- system and component efficiency rates before and after
- reportable incidents before and after
Benchmarking analysis between two nuclear power plants in Germany

In the scope of a project, processes and maintenance cost structures of German NPP A and B are compared. The goal of the project is to determine best practices with regards to detailed technical processes and overall maintenance costs. This approach of identifying costs from a divisional level and a detailed process level serves as a control function when assigning full costs to maintenance activities.

Determining relevant systems for the analysis

When determining relevant systems, the biggest contributors to maintenance costs need to be identified. A good measure is the 50% mark of systems that contribute most to the overall maintenance costs, which include material and contractors. These 50% of systems are called “cost-drivers”. In order to account for exceptional maintenance activities in certain years, the year 2001 was chosen to be representable for Plant A, and 2003 for Plant B (see APPENDIX A).

Divisional level approach

Data on maintenance costs can be extracted from the business administrative system used in the plants. 50% of the most expensive systems are to be identified and included in the benchmark analysis. In this case, data on cost was available separately for material and contractors on one side, and maintenance cost for internal staff on the other side. The latter was derived by conducting interviews among internal staff of plants A and B, determining the exact time spend on maintenance per system.

As suggested earlier, performing a standardization of these costs to fit the different characteristics of Plant A and B is essential. A detailed view on each of the systems needs to be generated. The following will give an example of how this detailed view should be conducted:

Example 1: Detailed view on system costs in system “emergency power supply”

The reason for different system costs (Plant A: € 689T, Plant B: € 932T) can partly be explained by the difference in numbers of diesel engines. Plant A has 5, Plant B 6. The cost of the system “emergency power supply” of Plant A therefore needs to be multiplied by 6/5 in order to fit these circumstances. The system cost in Plant A then yields € 689T x 6/5 = € 827 T, which reduces the difference between the Plants from € 243T to € 105T.

Example 2: Detailed view on system costs in system “documentation”

The delta in costs between Plant A and Plant B in system “documentation” of € 277T is based on the different manners of handling incident and defect notifications (IDN). Plant A documented 1029 IDNs, whereas Plant B only handled 433. While experiencing a comparable overall number of incidents, the difference in IDN numbers can be explained by determining the amount of incident the plants’ staff handles as an IDN and that of which it doesn’t.

Working with maintenance full cost

Total costs are defined as all costs involved in the selected activity, including:

- material
- contractors
- internal staff
- administrative services
- assessor costs

These costs can be identified by the plants’ business administration department for the selected cost-driver systems and other systems (see Table 2).

<table>
<thead>
<tr>
<th>Cost-driver systems</th>
<th>Plant A</th>
<th>Plant B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs for material and contractors</td>
<td>8,618</td>
<td>9,266</td>
</tr>
<tr>
<td>Costs for internal staff</td>
<td>4,374</td>
<td>5,611</td>
</tr>
<tr>
<td>Full costs</td>
<td>12,992</td>
<td>14,877</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other systems</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs for material and contractors</td>
<td>7,251</td>
</tr>
<tr>
<td>Costs for internal staff</td>
<td>7,413</td>
</tr>
<tr>
<td>Full costs</td>
<td>14,666</td>
</tr>
</tbody>
</table>

| Administrative services | 2,300 | 2,300 |
| Assessor costs | 1,800 | 1,800 |
| Total costs | 31,758 | 35,818 |
| Percentage full costs of cost-driver systems to total costs | 40.91% | 41.53% |

Table 2: Cost-drivers in Plants A and B (‘000 €)

This steps verifies the feasibility of selecting the designated cost-driver systems for the benchmark analysis. In case of a mismatch in the percentage full costs of cost driver systems to total cost, the selection of systems needs to be adjusted.

Prices on a divisional level per activity

After determining the full costs of cost-driver systems, cost-driver systems that do not show a substantial difference in full costs can be eliminated from the analysis. In the following this paper will focus on the systems:

- emergency power supply
- feed-water conveyance
- cooling water cleaning
- main cooling water system
- reactor pressure vessel
- cooling system.

It is essential to break down the full costs of these systems to a comparable measure. In this case, full costs as determined above should be divided by the number of the specific activities, namely

- incident and defect notifications (IDN)
- recurring testing / activities (RTA) with or without work sheet

It to yield an average full cost per activity. The number of activities is displayed in Table 3.
Table 3: Number of activities and full costs in Plant A and B in '000 €

Assuming that a RTA with a work sheet is twice as expensive as the RTA without the work sheet, average full costs for each activities are displayed in Table 4.

Table 4: Average full cost of activities in €

From a divisional perspective, the average price of an IDN calculated on a full cost basis is € 8.740, € 3.760 for a RTA with worksheet and € 1.880 for a RTA without worksheet. These numbers serve as control values for the next step, the determination of costs from a detailed technical process level.

Process level approach

The process level approach requires a detailed look at work processes within identified cost-driver systems. In addition to deductively deriving average full costs in the divisional approach, each technical process including material costs, contractor costs and internal staff costs that sum up to the full cost of the process is to be examined and quantified.

The example process data in APPENDIX B is entered into the maintenance activity database.

Activities need to be quantified for each component and standardized to fit the benchmark database. Database queries are then executed to display the best-practice activity and the respective full cost. In the same process, the cost-cutting potential for each plant is summed up and the respective best-practice activities provided for the plants.

The process level approach is a very detailed, accurate process that binds resources for collecting documents, discussions on standardization issues, and allocating manpower. However, it is an essential part of the benchmark analysis that allows for direct results and swift implementation in the plants.

The optimization potential of adapting the plants processes to the best-practices of our example plants A and B in two select systems can be seen in Table 5.

Table 5: Optimization potential in '000 €

Integral benchmark

Best-practice activities derived from the process level approach are compared with the full costs calculated in the divisional level approach to verify their significance and accuracy. The level of conformity between the two approaches yields a measure for the quality of the performed benchmark analysis. These activities combined with KPI determined with the help of process data reconciliation yield an optimal state of the plant with regards to safety, production and cost efficiency, see APPENDIX C.

The benchmark analysis in this example resulted in an overall optimization potential of € 4.1 MM per year to be achieved in by reducing contractor services. As an average, utilities who had integral process benchmark analysis performed on their plant, were able to cut cost worth 12.4% of total costs.

CONCLUSION

Integral benchmark analysis enables plant operators to take a look at the real cost situation within the plant’s maintenance processes. A two-way approach to determining process full costs results in the formulation of detailed process benchmarks. Ensuring comparability through standardization, best-practice NPP processes are selected and sub-optimal processes adjusted to the newly found benchmark. The integral process benchmark analysis needs to be performed by independent consultants with in-depth knowledge of technical processes in various NPP to ensure an objective and useful outcome.

REFERENCES


Appendix A: Identified cost-drivers in Plants A and B (’000 €)

<table>
<thead>
<tr>
<th>Cost-drivers</th>
<th>Plant A</th>
<th>Plant B</th>
<th>Plant A</th>
<th>Plant B</th>
<th>Plant A</th>
<th>Plant B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor pressure vessel</td>
<td>608</td>
<td>585</td>
<td>456</td>
<td>636</td>
<td>961</td>
<td>1,220</td>
</tr>
<tr>
<td>Cooling system</td>
<td>210</td>
<td>506</td>
<td>191</td>
<td>263</td>
<td>401</td>
<td>769</td>
</tr>
<tr>
<td>Turbine</td>
<td>537</td>
<td>572</td>
<td>401</td>
<td>401</td>
<td>938</td>
<td>973</td>
</tr>
<tr>
<td>Feed water conveyance</td>
<td>216</td>
<td>681</td>
<td>452</td>
<td>216</td>
<td>668</td>
<td>897</td>
</tr>
<tr>
<td>Live-steam system</td>
<td>456</td>
<td>574</td>
<td>526</td>
<td>425</td>
<td>982</td>
<td>999</td>
</tr>
<tr>
<td>Coolant water cleaning</td>
<td>82</td>
<td>312</td>
<td>299</td>
<td>333</td>
<td>391</td>
<td>645</td>
</tr>
<tr>
<td>Main cooling water system</td>
<td>1,085</td>
<td>425</td>
<td>440</td>
<td>427</td>
<td>1,526</td>
<td>852</td>
</tr>
<tr>
<td>Emergency power supply</td>
<td>312</td>
<td>451</td>
<td>377</td>
<td>481</td>
<td>689</td>
<td>932</td>
</tr>
<tr>
<td>Low voltage auxiliary power</td>
<td>408</td>
<td>390</td>
<td>60</td>
<td>82</td>
<td>468</td>
<td>472</td>
</tr>
<tr>
<td>Final control element / variable speed drive</td>
<td>584</td>
<td>284</td>
<td>35</td>
<td>627</td>
<td>619</td>
<td>911</td>
</tr>
<tr>
<td>Reactor protection</td>
<td>27</td>
<td>453</td>
<td>190</td>
<td>320</td>
<td>217</td>
<td>773</td>
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<tr>
<td>Control electronics</td>
<td>985</td>
<td>427</td>
<td>196</td>
<td>217</td>
<td>1,091</td>
<td>644</td>
</tr>
<tr>
<td>IT / Computers</td>
<td>1,035</td>
<td>833</td>
<td>323</td>
<td>347</td>
<td>1,358</td>
<td>1,180</td>
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<tr>
<td>Radiation protection</td>
<td>511</td>
<td>454</td>
<td>14</td>
<td>14</td>
<td>525</td>
<td>468</td>
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<tr>
<td>Decontamination</td>
<td>544</td>
<td>654</td>
<td>18</td>
<td>19</td>
<td>562</td>
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<tr>
<td>Documentation</td>
<td>436</td>
<td>525</td>
<td>486</td>
<td>122</td>
<td>924</td>
<td>647</td>
</tr>
<tr>
<td>Recurrent testing, NDT</td>
<td>392</td>
<td>550</td>
<td>0</td>
<td>24</td>
<td>392</td>
<td>574</td>
</tr>
<tr>
<td>Recruitment machine shop</td>
<td>281</td>
<td>590</td>
<td>0</td>
<td>0</td>
<td>281</td>
<td>590</td>
</tr>
<tr>
<td>Sum over selection</td>
<td>8,618</td>
<td>9,266</td>
<td>4,374</td>
<td>4,953</td>
<td>12,992</td>
<td>14,219</td>
</tr>
</tbody>
</table>

**Percentage of total cost in %**

| Percentage of total cost in % | 54.31% | 51.80% |
### APPENDIX B: Maintenance activity database

<table>
<thead>
<tr>
<th>Plant</th>
<th>Activity</th>
<th>Component</th>
<th>Component / activity code</th>
<th>Material</th>
<th>Plant condition</th>
<th>Interval</th>
<th>Assessor</th>
<th>Testing object</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant A RTA</td>
<td>Feed water pump</td>
<td>E 02 RL 00 473.9</td>
<td>M B</td>
<td>4a</td>
<td>a</td>
<td>Reactor feed-water pump RL11-31D101</td>
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<td></td>
</tr>
<tr>
<td>Plant B RTA</td>
<td>Feed water pump</td>
<td>QBL 4.13</td>
<td>1.8 16.4</td>
<td>X</td>
<td>a</td>
<td>Qualified operational electrical engineering</td>
<td></td>
<td></td>
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<tr>
<td>Plant B RTA</td>
<td>Feed water pump</td>
<td>RL 10.2</td>
<td>1.4 17.10</td>
<td>B</td>
<td>3m</td>
<td>a</td>
<td>Deactivation of reactor feed pumps from reactor protection</td>
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<tr>
<td>Plant B RTA</td>
<td>Feed water pump</td>
<td>QBL 3.2</td>
<td>1.8 16.3</td>
<td>B</td>
<td>a</td>
<td>a</td>
<td>Reactor feed pumps</td>
<td></td>
</tr>
<tr>
<td>Plant B RTA</td>
<td>Feed water pump</td>
<td>RL 81.2</td>
<td>3.4 7.81</td>
<td>St</td>
<td>4a</td>
<td>a</td>
<td>Operational protection incitation RL 13</td>
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<td>3.4 7.81</td>
<td>St</td>
<td>4a</td>
<td>-</td>
<td>Operational protection incitation RL 23</td>
<td></td>
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<tr>
<td>Plant B RTA</td>
<td>Magnet valves of rapid draining</td>
<td>RL 10.2</td>
<td>1.4 7.10</td>
<td>BE</td>
<td>3m</td>
<td>a</td>
<td>Deactivation of reactor feed pumps from reactor protection</td>
<td></td>
</tr>
</tbody>
</table>

### APPENDIX C: Overview on Integral Industry Process Benchmarking

#### KPI
- **Minimized costs / Optimized processes**

#### Business Processes
- **CLIENTS’ PLANT**
  - Identification of cost drivers
  - Calculation of activities’ full cost

- **VIRTUAL BEST- PRACTICE PLANT**
  - Identified Best-Practice business processes
  - Benchmarked full-costs of activities

#### Technical Processes
- **CLIENTS’ PLANT**
  - Determination of real process full cost
  - Identification of processes according to their economical and safety feasibility

- **VIRTUAL BEST- PRACTICE PLANT**
  - Identified Best-Practice processes
  - Benchmarked full-costs of processes

#### KPI
- Analysis of costs on a divisional level
- Performance of a Best-Practice analysis on a process level