Power Plant Cost and Performance Analysis When Operating in Base Load and Flexible Operation Modes With Increasing Renewables

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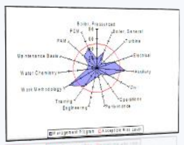
- **Engineering & R&D company based in Surrey, UK**
- **Power & Process Plant Inspection & Condition/ Life Assessment**

Specialist Institutions → Research → etd ← Knowledge ← International Experts

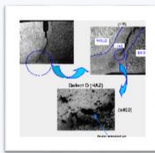
Application

Conventional Steam plant, CCGT, HRSG, Petrochemical, Refining + other industrial sectors

- Collaborative R&D / Technology Development
- Plant Integrity
- Plant Services
- Training & Technology Transfer

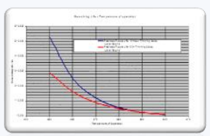


RBI, RBM, FFS

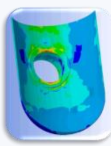


Weld Repair Expertise

- Life Assessment
- Welding & Repairs
- Heat Treatment
- Int. P91 User Group



Crack Assessment (RLA, FFS)



Stress Analysis – CAESAR Pipeline Stress Analysis / FEA

ETD's Products / Software

A compendium of lifing procedures - for power plants / HRSGs

e-Atlas - database of ageing microstructures with 11,000 replicas

CRACKFIT Crack Assessment Procedure & Software

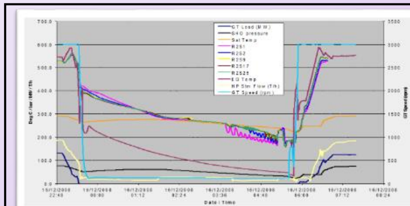
MAS Maintenance Advisory Software

- Boiler Lifing Procedure
- HRSG Inspection, Monitoring, Repair & Lifing Procedure
- Boiler tube Failure Management Guidelines
- Procedures for PP/ CCGT Preservation during shut down

Cyclic HRSG/CCGT

Assessing plant cyclic capability:

- Materials Design & Performance
- Start up/shut down – technical parameters & costs
- Condensate calculations
- Allowable no. of cycles
- Damage mechanisms
- Life assessment
- Cost modelling



Effects of cyclic operation on both conventional power plants and CCGT's- with regard to damage, technical and cost issues

Technical & Cost Analysis for Component Replacement in Ageing Plant

Performance / integrity of weld repaired components in ex-service conditions

Why is it important to know the cycling impact?

High demand and competition in the power generation market

Increase of cyclic or two-shift operation

Cyclic operation requires units' high flexibility

Plants which cannot respond to load changes are penalised

“Plant flexible operation” or “cycling”

- **Two-shifting** - plant is started up and shut down once a day.
- **Double two-shifting** - plant is started up and shut down twice a day.
- **Load-following** - plant is on for more than 48 hours at a time - varies output as demand changes.
- **On-load cycling** – plant, e.g. operates at base load during the day and then ramps down to minimum stable generation overnight.
- **Weekend shutdown** - plant shuts down at weekends. This is often combined with load-following and two-shifting.
- **Sporadic operation** - for periods of under two weeks followed by shutdown for more than several days.

Two-shifting

- Most common form of cycling.
- Also implies that the plant will be shut-down from Friday night to Monday morning.

Two-shifting is considered to be the most damaging form of cycling.

On Load Cycling

- On-load cycling is defined as ramping from minimum (or within 15% of minimum) and maximum (or within 15% of maximum) generation, at or close to the unit's maximum ramp rate.

- The analysis for on-load cycling should be based on the minimum/ maximum generation values and ramp rates data.

- **Plant cycling problem is getting *worse* with the increasing use of <u>hydros</u> & <u>renewables.</u>**

- **Both of the above can fluctuate rapidly with time , especially wind and sun which can disappear within minutes.**

We need to be prepared for even more severe load fluctuations in the future - due to the increasing use of renewables Worldwide

Some of the cycling related problems

- Superheaters and reheaters, due to the need to start up "against the clock" can experience *temperature excursions significantly above design.*

- Operating equipment to process and supply fuel is affected.

- General increase in wear and tear.

- Operation of water treatment plant.

- Re-training of staff

Plant Cycling Issues

- ETD have carried out *single* and *multi-client projects* addressing cycling technical and cost issues for utilities & plants in the UK, Ireland, France, Netherlands, Spain, USA, Canada and Malaysia.
- Have produced *Review Reports* on CCGT / HRSG and Conventional PP cycling.
- Some of ETD Reviews of cycling issues have been described as the 'bible' of PP cycling.

Main Objectives

1. Plant owners/operators need to understand technical issues and costs associated with the cycling. Quite complex as this could vary with plant *design, age, size and materials* etc.

2. Reduce cycling related cracking/ failures by incorporating modifications to plant and to undertake necessary inspection, monitoring etc.

3. Understand staff training needs for the successful operation of cyclic plant.

4. Understand creep-fatigue behavior of individual materials & plant design.

5. From cost modeling ETD predicts O&M budgets for the next few financial years.

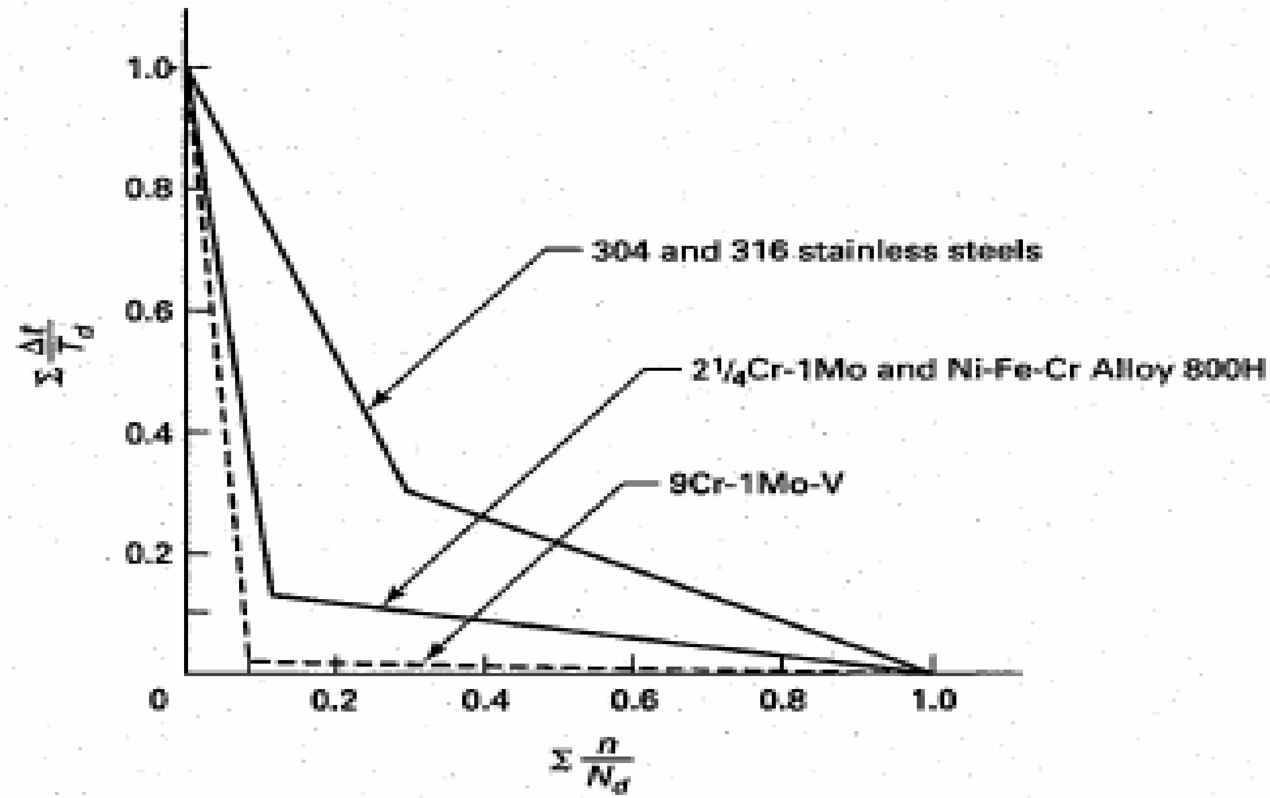


FIG. T-1420-2 CREEP-FATIGUE DAMAGE ENVELOPE

Creep-fatigue design life limits for some of the high-temp. alloys

(ASME Nuclear Section III, 2004)

About the Costs

ETD's experience shows that vast majority of plant operators have poor cost allocation systems such that in general only a broad high level O&M (Operation and Maintenance) annual costs are obtainable.

- A significant variation in the O&M cost for similar large units can occur.

- As the need to accurately cost two shifting and load following increased, some organisations in the industry started to examine in more detail the factors associated with the plant cyclic operation.

ETD has *focused* on the factors which can lead to increased maintenance and the need to replace equipment even before going into enhanced cycling.

This is so since, in principle, it is relatively simple to identify the day to day increases in the above costs due to two shifting and load following operation.

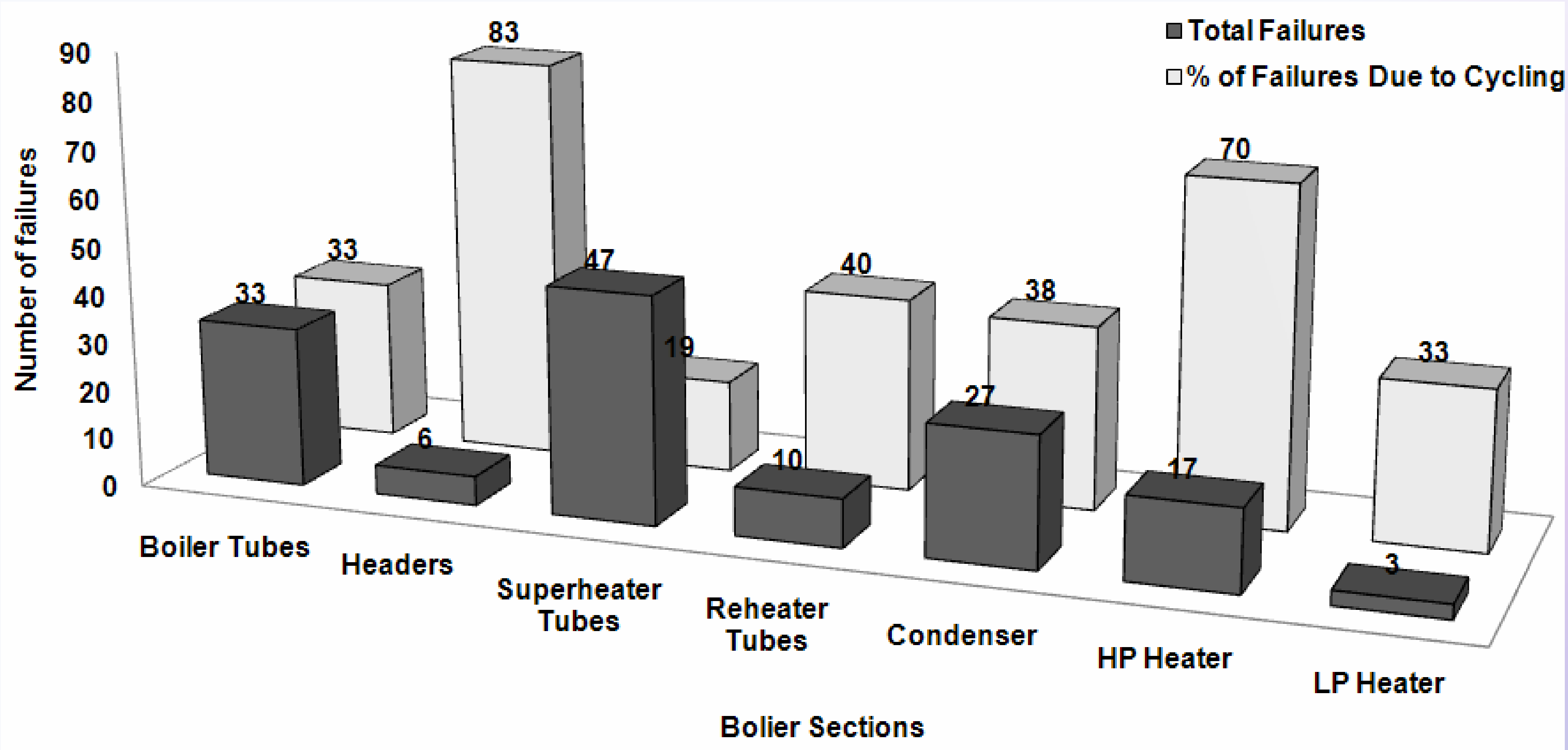
Factors Affecting Cost

A change to cyclic operation can potentially result in:

- Increased capital spend for component replacement.
- Increased routine O&M cost from higher wear and tear.
- Lower availability due to increase in failure rate & increased outage time (with associated lost generation costs).

Plant specific factors that can influence cost include:

- The overall design of the plant - drum type or once through boiler and the layout e.g. bypasses etc.
- Individual design of major components – materials, thickness etc.
- The way the plant is operated.
- The quality of the water chemistry.
- The size and age of the plant.
- Previous maintenance quality and philosophy.
- Modifications made to the plant before it is assigned to the cyclic operation regime.



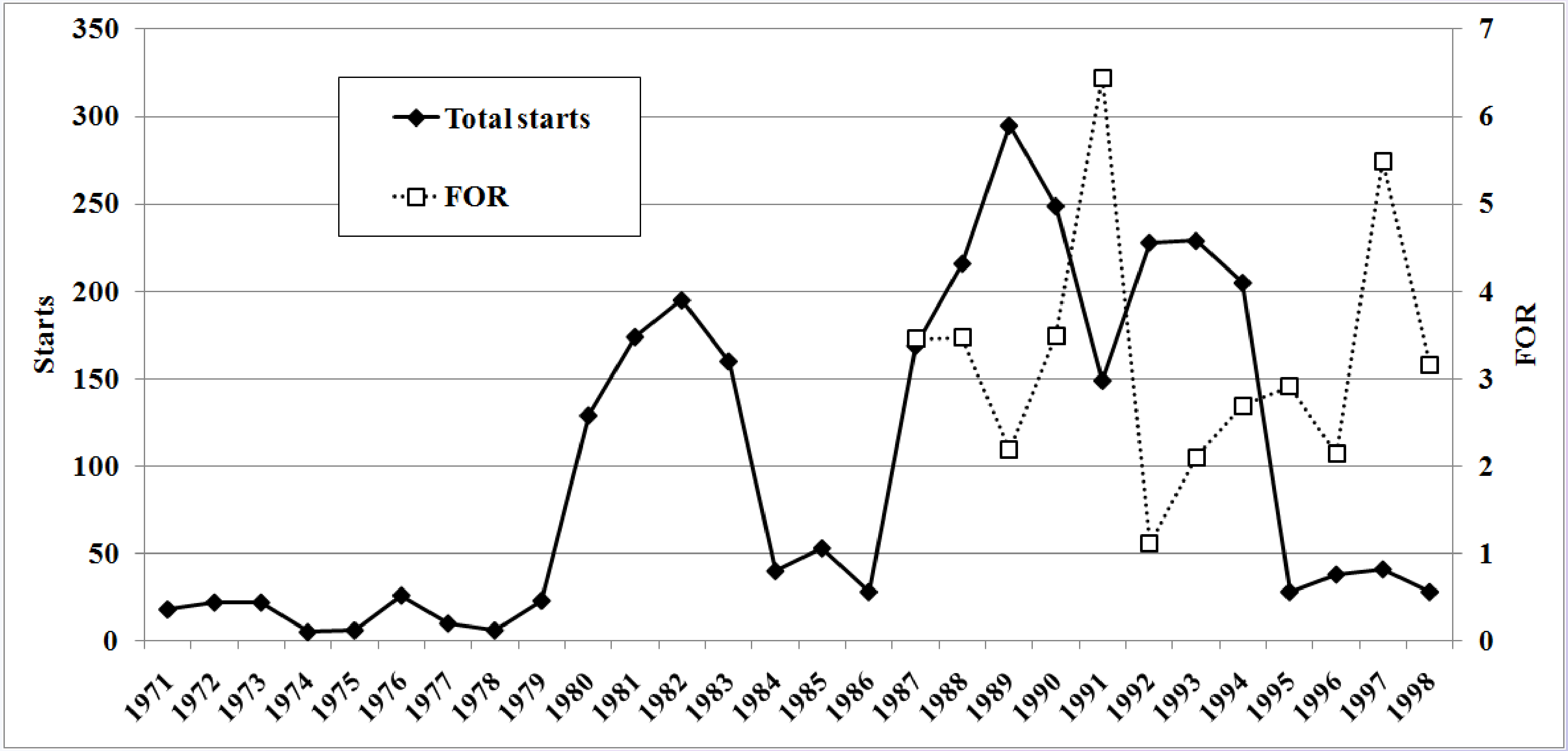
Breakdown of cycling related failures

Forced Outage Rates

Influence of Cycling on Forced Outage Rate:

- The impact of cycling can lead to more operating problems and a greater rate of key component failure.
- The forced outage rate will therefore increase, but the difficulty lies in determining by how much and when.

Relationship between number of ‘starts’ and FOR *(small Gas-fired Unit)*



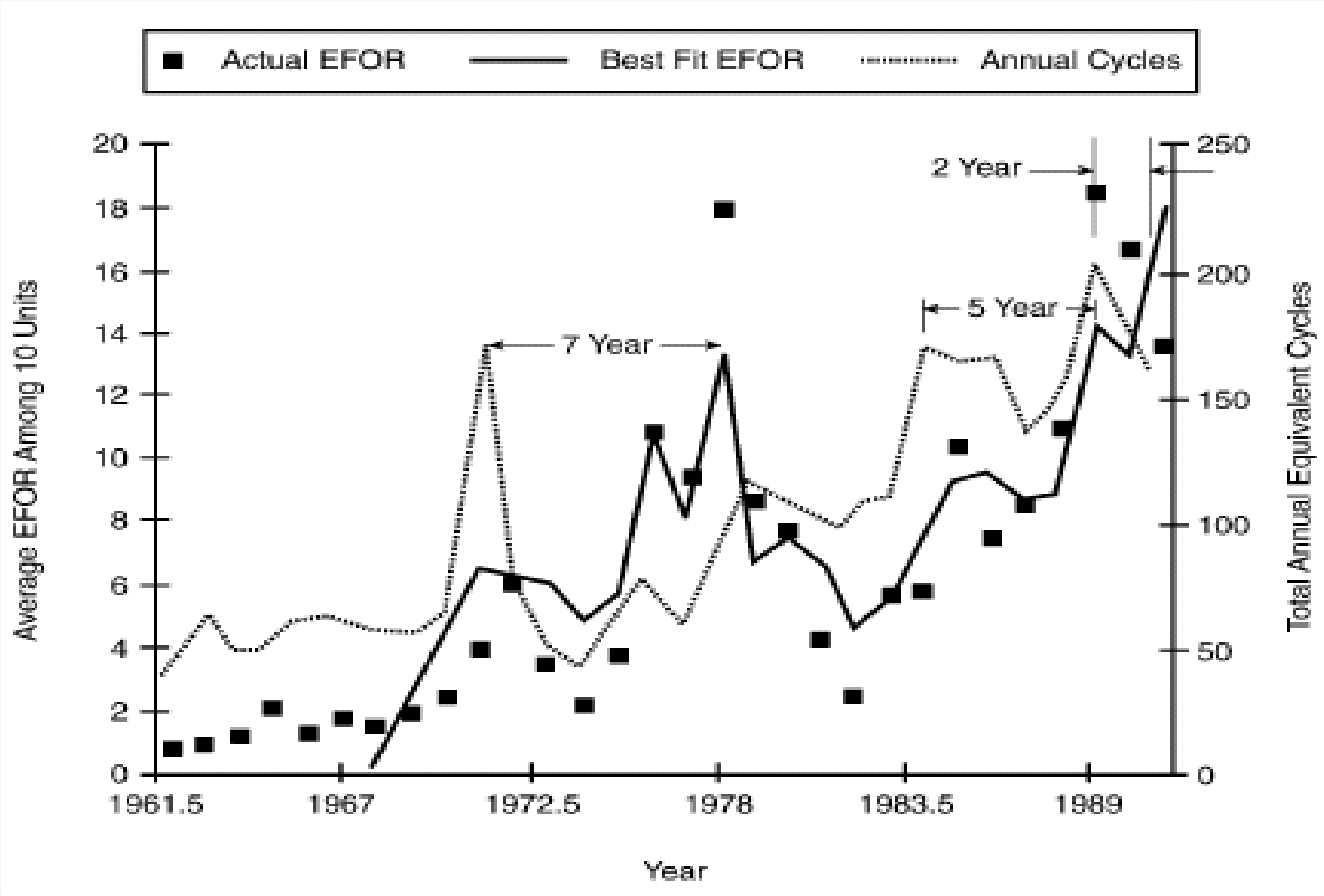
Forced Outage Rate

- A substantial increase in the number of starts (cyclic operation) will result in more failures.
- But this will not occur until a significant period of additional service has accumulated.
- However, our experience shows that it is difficult to find a *clear relationship* between the degree of FOR and the number of starts.
- The extent of FOR will be dependant on several factors, e.g. quality of maintenance, the age and design of plant.
- FOR will, therefore, be subject to a large variation.

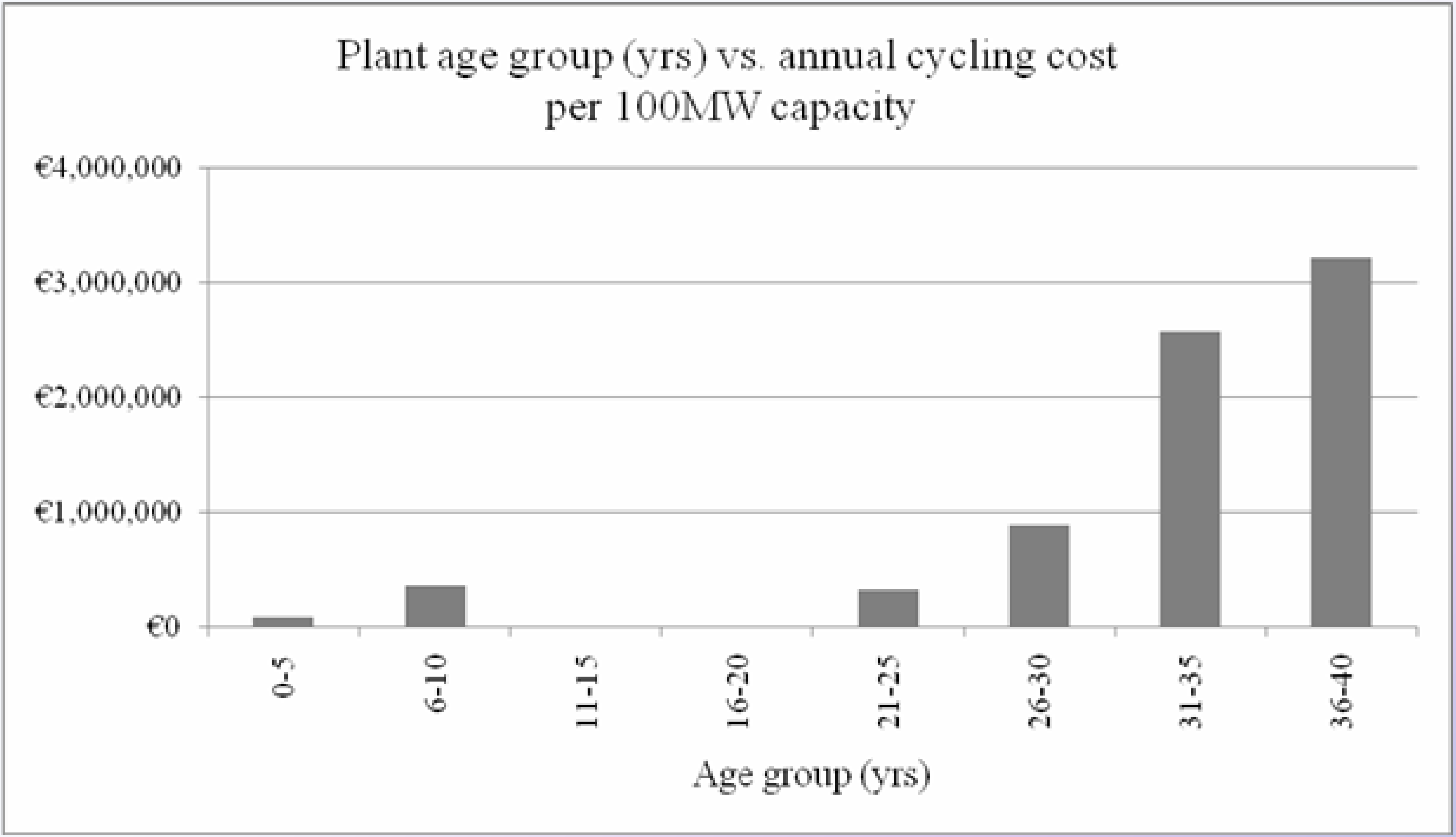
Equivalent Forced Outage Rate

- FOR was originally designed for base load operation.
- It does not take into account the number of starts but only the service hours.
- It is therefore necessary to apply the EFOR for two shifting plants.

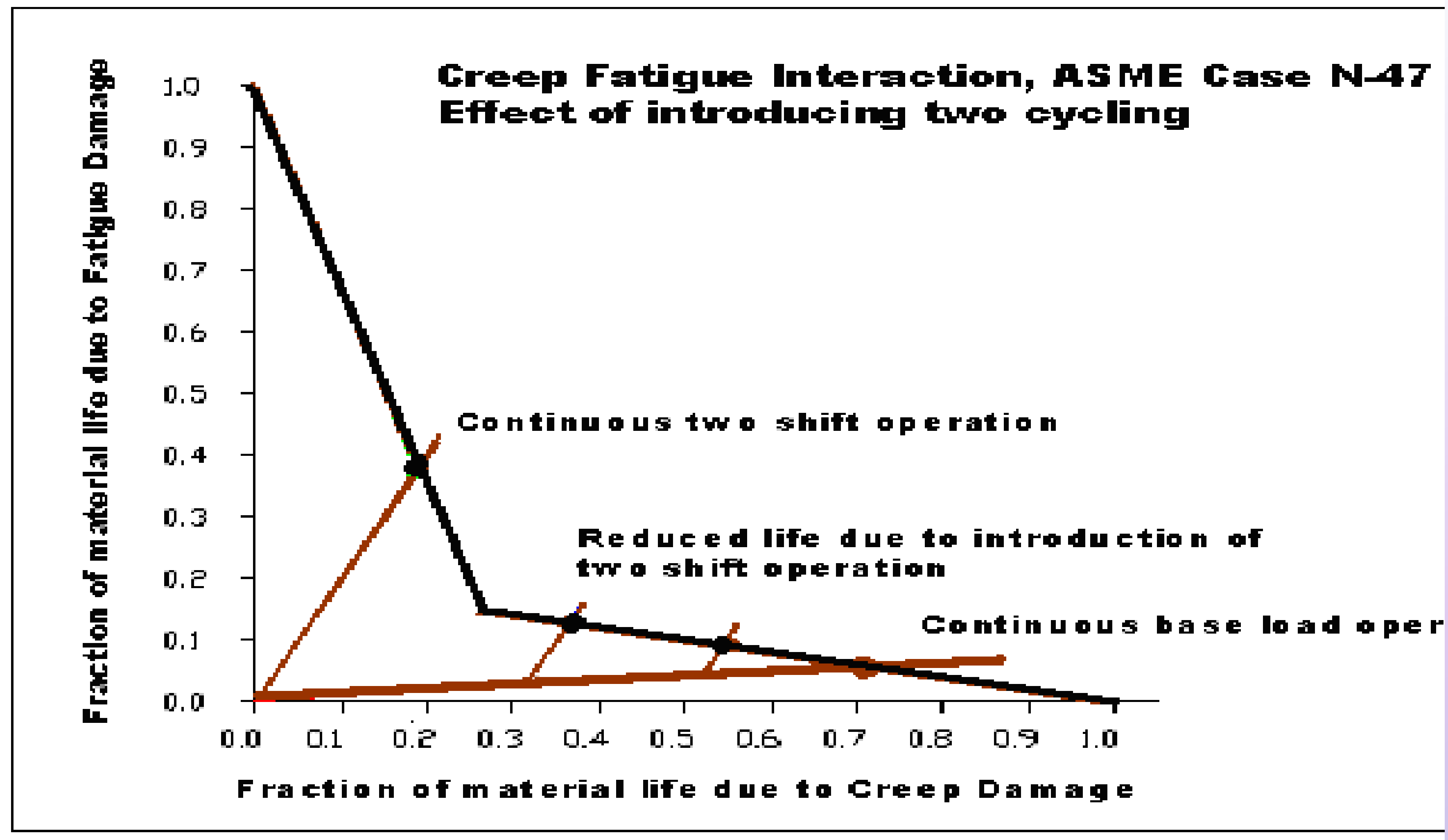
There is a correlation between the Equivalent Forced Outage Rate (EFOR) and the number of annual starts



Relationship between cycling and EFOR



Plant age group (yrs) vs. annual cycling cost
per 100MW capacity
€4,000,000
€3,000,000
€2,000,000
€1,000,000
€0
0-5
6-10
11-15
16-20
21-25
26-30
31-35
36-40
Age group (yrs)



Interaction and consequences of creep and fatigue (based on ASME N-47) for a typical power plant steel (2.25Cr1Mo)

Operation & Maintenance

A typical method of estimating cycling costs is centred on evaluation of *historical data*.

- If good historical O&M cost data is available then it is possible to establish a mathematical relationship that will be able to predict the probable short-term future costs.
- One approach is to utilise the previous years' costs for the plant under review.

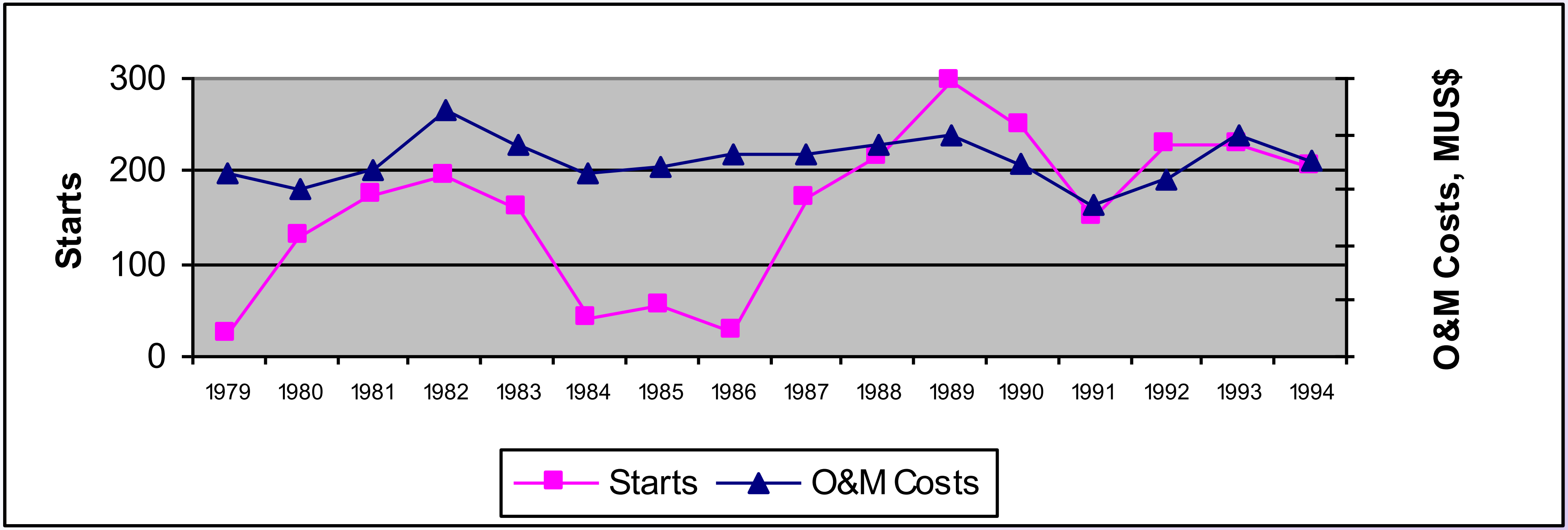
Operation & Maintenance

- The critical aspect of the predictive capability of any model is whether it will predict cost changes associated with changes in operating mode rather than just modelling general trends.

- Thus, a critical evaluation of equipment characteristics and likely performance under cycling conditions is needed.

- This is done in conjunction with an assessment of inspection, maintenance and replacement issues which will give more reliable estimates.

An example of historical O&M cost data together with unit starts



- Interestingly this Figure infers that cyclic operation does not have a major impact on the O&M trend.

- This suggests that other factors e.g. management strategies for reducing staff numbers, changes in maintenance methods etc. may be more important in determining the annual budgets.

Capital and Major Item Replacement Costs

The cost of, say, replacing a header will be different in different countries due to:

- Different staffing levels
- Different working methods
- Different OEM charging practices

Heat Rate & Auxiliary Costs

Efficiency is lower under start-up, shutdowns and low load conditions.

General wear and tear e.g. worn seals, damaged insulation, and turbine blade erosion etc. will also have a cumulative effect on the efficiency.

Heat Rate & Auxiliary Cost

- One of the ETD surveys indicated that heat rate testing was performed fairly frequently.

- Unfortunately, these tests are normally carried out under ideal, constant load conditions and typically under an optimised mode of operation.

- Readings are taken at very efficient turbine valve points and hence do not reflect the actual daily operation of a cycling unit where operation dynamics means relatively long periods at less than optimum fuel burn.

Heat Rate & Auxiliary Cost

- Meanwhile it is possible to compare the actual fuel burn with plant output and relate this to the effects of cyclic operation.
- It is estimated that the % of the total start-up cost that should be included to account for non-optimum heat rate conditions is around 15%-20%

Modeling of Costs

- In order to be able to predict the cost of cyclic operation in all of its possible combinations ETD has developed a model.

- The model determines with reasonable accuracy the overall impact of any given two shift or load variation cycle on the costs that will result both in the short and the long term.

Modeling of Costs

The main elements comprising such models can be summarised as follows:

- Establish historical cycling pattern at a high level (e.g. hourly MW data).
- Collate, analyse and 'smooth' available historical cost data.
- Establish a base cycle to compare and relate to actual cycles.
- Introduce a damage accumulation model which includes terms covering steady state (creep), cyclic (fatigue) and corrosion conditions.
- Determine the cost of a base cycle and, via the degree of deviation of the actual cycle from the base case, estimate the cost of each type of start or load change.

ETD Criteria for Start-up

- Considerations
  - In terms of damage caused by starting a unit, a **hot start** (where the unit has typically been off-line for less than eight hours) causes least damage.
  - A **cold start** (typically off-line for more than 48 hours) causes most damage.
  - To allow for this variation in the effects of different types of start, an equivalent hot start (EHS) value is calculated for each unit, based on the ratios between the cold, warm and hot start ups.

Maintenance & Operation of Equipment

- Many utilities are nowadays focused on the plant performance and are constantly worried with the possibility of not being capable of meeting the market demand. They need to understand that:

- 1) Good plant equipment maintenance and operation achieves far greater results than just plant thermal efficiency improvement resulting in the **development of new maintenance philosophies and techniques**.

- 2) To achieve this ETD makes recommendations to its clients for the **improvement** of plant management, operation, monitoring, plant design modification, staff levels and training to optimize plant life cycle costs.

Other Factors to Reduce Cyclic Plant Costs

- Other factors to consider are:
  - Long Term Service Agreements and their Limitations.
  - Reliability Centered Maintenance (RCM) and Condition Monitoring.
  - Risk Based Maintenance.
  - Total Productive Maintenance (TPM).
  - Performance-Based Total Productive Maintenance (PTPM).

Benchmarking of Baseload and Cycling Plants

1. Use of cost and performance benchmarking analysis for a utility
2. Top Down Analysis Considerations
3. Plant Performance Analysis
4. Recent findings of the effects of starts on CCGT maintenance costs using top down statistical analysis
5. Projected cost impact of renewables on fossil units within a system
6. Engineering drivers behind cost increases due to cycling

- **Recently a utility with 12 power plants located in North America was looking for an increase in profitability**
- **The utility approached ETD to assess the maintenance strategy for each of its individual plant**

- **ETD's performance assessment involved:**
  - **Assessing operational, reliability and financial level of performance of individual plants**
  - **Benchmarking individual plant performance against ETD performance database and against each other in the utility's fleet.**
  - **Performing gap analysis (where required)**
  - **Establishing achievable targets and providing recommendations**

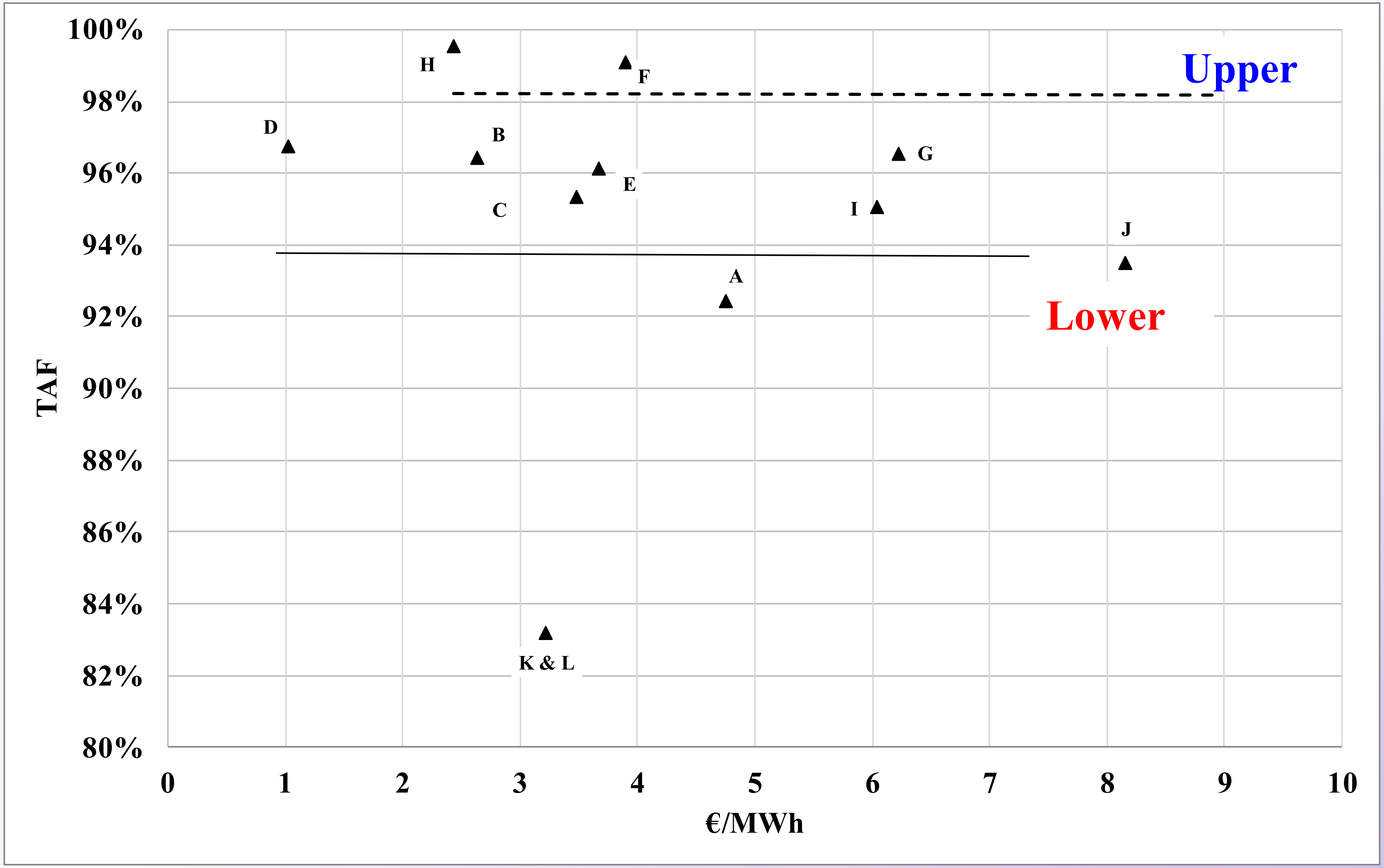
ETD’s Assessment Strategy

- Collecting Operational and Maintenance questionnaire based data (questionnaire designed and issued by ETD)
- Plant group benchmarking
- Development of performance models using statistical data analysis to determine upper and lower (range) level of performance from the database
- Superposition of the client’s plant data onto the benchmarked data
- Analysing the performance and identify gaps if any.

Areas of Assessment

- **The maintenance assessed performance in this project** *Included:*
  - ***Operational Performance***
    - ***Lifetime (Net) Generation (LNG)***
    - ***Electrical Availability Factor (EAF)***
    - ***Steam Availability Factor (SAF)***
  - ***Reliability Performance***
    - ***Forced Outage Factor (FOF)***
    - ***Planned Outage Factor (POF)***
    - ***Maintenance Planning and Strategy (POF vs FOF)***
    - ***Failure or Breakdown Frequency and Typology***
  - ***Financial Performance***
    - ***Day-to-Day Maintenance Costs (DDMC)***
    - ***Forced Outage Maintenance Cost (FOMC)***
    - ***Planned Outage Maintenance Cost (POMC)***
    - ***Overhaul Cost (OC)***

Total Availability Factor (TAF)



Total Availability Factor (TAF) - 5 years average and Total Maintenance Cost (TMC) comparison for each individual plant

Conclusions (1)

- It is usually difficult to obtain cost information for detailed analysis.
- Models have been developed by ETD to predict the cost of cycling for the client specific plants.
- It is necessary to spend effort in quantifying the impact of many factors that influence plant reliability and maintenance requirements.

Conclusions (2)

- Improvements in estimating the cost of cycling is possible with better co-operation and sharing of cost information within the industry. ETD’s Group Sponsored Projects (GSPs) are helping to achieve this where we have collected data for over 120 plants.

- With current trends towards better allocation of O&M costs, significant improvements should be possible in the accuracy of cost predictions and in identifying the value of different maintenance techniques.

Conclusions (3)

Apart from work for the individual plants and utilities, ETD has carried out cyclic cost work for Electricity Regulators (government bodies) in Ireland and the UK, and for groups of utilities in the USA through EPRI, and in Canada through CEATI (Canadian Electricity Association).

European Technology Development

A Bridge Between Industry and Research