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Technical Guidance Document – 2024 Revision: Instrumentation for monitoring and control of cycle chemistry for the steam/water circuits of fossil-fired, combined cycle, and industrial power plants

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Summary

This Technical Guidance Document was first issued in 2009 and revised in 2012 and 2015. This 2024 revision includes a small number of updates and clarifications. These do not constitute significant changes to the scope of the document or to the guidance contained.

In order to achieve suitable chemical conditions in steam/water circuits, it is essential to establish reliable monitoring of key parameters on every plant. This enables the demonstration of operation within cycle chemistry targets, and alerts the operators to the need to take corrective action when the target conditions are compromised.

This technical guidance document considers conventional fossil, combined cycle / HRSG, and industrial plants and identifies the key instrumentation and monitoring techniques required for each plant type and cycle chemistry treatment. It is emphasized that this is an IAPWS guidance document and that, depending on local requirements, the use of simpler instrumentation may be adequate, whereas more complex techniques and instrumentation may be necessary when specific issues arise.

This Technical Guidance Document contains 26 pages, including this cover page.

Further information about this Technical Guidance Document and other documents issued by IAPWS can be obtained from the Executive Secretary of IAPWS (Dr. R.B. Dooley, bdooley@iapws.org) or from http://www.iapws.org.

Contents

1. Nomenclature and Definitions

Term	Alternative or Acronym	Definition
All-volatile Treatment	AVT AVT(R) AVT(O)	Conditioning regime in which only volatile alkalizing agents are used (commonly ammonia – volatile amines may also be employed). May be either: Reducing conditions (added reducing agent) or Oxidizing conditions (residual oxygen present)
Attemporator		Device for controlling superheater and reheater outlet temperatures by spraying feedwater (or condensate or degassed demineralized water) into steam.
Caustic Treatment	CT	Conditioning regime for drum boilers in which alkalinity is achieved by dosing with NaOH.
Condensate		Water that derives from condensation of steam after passage through a steam turbine or process heat exchanger. (Monitored at the Condensate Pump Discharge (CPD) and Condensate Polisher Outlet (CPO))
Conductivity	Specific Conductivity Direct Conductivity	Electrical conductivity of an unmodified water sample.[1]
Conductivity after cation exchange	Cation Conductivity Acid Conductivity CACE	Conductivity of a water sample after passage through a strongly acidic cation exchanger in the hydrogen form.
Degassed conductivity after cation exchange	Degassed Cation Conductivity DCACE	Conductivity after cation exchange of a sample from which volatile weak acids (predominantly carbonic acid) have been stripped.
Drum boiler		Boiler in which steam (generated in heated evaporator tubes) is separated from water in a horizontal pressure vessel. The liquid phase is recirculated to the evaporator.
Fast Start Combined Cycle / HRSG Plant		Combined cycle plant able to have accelerated hot, warm, and cold starts.
Feedwater		Water that is being pumped into a boiler or HRSG to balance the steam production.

Term	**Alternative or Acronym**	**Definition**
Heat Recovery Steam Generator	HRSG	Plant that generates steam using heat from the exhaust gas of a combustion (gas) turbine.
Make-up Water		Water which is added to compensate for losses of water and steam from the system.
Once-through boiler or HRSG	Benson Boiler	Boiler in which output steam is generated from input water by evaporation to dryness without recirculation.
Oxidation/Reduction Potential	ORP	Electrochemical potential of an inert electrode responding to the concentrations of oxidizing and reducing agents in a water sample.
Oxygenated Treatment	OT or CWT	Conditioning regime in which alkalizing agents and oxygen are added. (OT = oxygenated treatment, CWT = combined water treatment)
Phosphate Treatment	PT	Conditioning regime for drum boilers in which alkalinity is achieved by dosing a sodium phosphate compound or blend of compounds.
Total Organic Carbon	TOC	Concentration in aqueous solution of the carbon present in organic molecules and ions. (Excludes carbon present in carbonates, bicarbonates, and other inorganic species.)

2. Introduction

Safe, reliable operation of large steam raising and power generating plants depends upon the establishment of chemical conditions throughout the steam–water circuit that minimize the corrosion of system components and suppress the formation of deposits. The chosen chemical treatments and instrumentation will depend upon the details of plant type, circuit design, metallurgy, physical parameters (temperatures, pressures, heat fluxes, etc.) and intended operational mode of the plant (base, medium or peak load operation, frequent starts, and plants that are required to fast start after different shutdown periods). In all cases, it is essential to be able to measure the key chemical parameters and to take action on the basis of these measurements to ensure that chemical targets are achieved.

This technical guidance document considers conventional fossil-fired, combined cycle/HRSG, and industrial plants and identifies the key instrumentation and monitoring techniques required for each plant type and cycle chemistry treatment. Thus, for all systems there is a **Minimum Key Level of Instrumentation**. The document also considers **Optional Additional Instruments**, not essential for all plants, but which may provide further useful information to plant operators. Particularly important cases are for plants that are required to fast start and to frequently cycle (or two-shift). As an example, during fast start situations a combined cycle plant could be required to reach full load from gas turbine (GT) ignition in under 30 minutes following a unit shutdown of eight hours or less. This IAPWS document provides guidance on how best to monitor steam purity to demonstrate that it is suitable for admission to the steam turbine with minimal delays to startup times and, additionally, how best to set up on-line monitoring to detect serious cycle contamination during startups. The document represents the accumulated experience of the IAPWS Power Cycle Chemistry (PCC) Working Group with representation from 23 countries.

It is important that the operators of a plant consider the following items in developing a Minimum Key Level of Instrumentation:

1. Every plant should have a minimum level of continuous instrumentation which can uniquely identify the key parameters and drivers to each and every failure/damage mechanism which can occur in that plant. In other words, the instruments should relate to providing reliability and not necessarily to only chemistry monitoring of individual locations/parameters around the cycle.
2. The Minimum Key Level of Instruments does not necessarily only analyze the chemistry locally but needs to provide sensitivity analysis for the cycle in the event of a defective or out of service instrument. Thus, an instrument within the minimum key level is backed up by instrumentation at locations on either side of the specific instrument so that in the event of a serious contamination the operator does not need to take time to validate the reading of an individual instrument.
3. The Minimum Key Level of Instruments should provide complete assurance to an operator without that operator or their team having to go into the plant to "check" an instrument or to take a grab sample. This relates to point 2.
4. The Minimum Key Level of Instruments should all be audibly alarmed in the control room or on the distributed control system.

Chemical instrumentation can be divided into two categories:

On-line instruments: These give a continuous record of conditions and can be used to provide alarm signals to stimulate operator intervention if the parameters that they are measuring fall outside a pre-defined target range. In some instances, the output from such instrumentation may be used in automatic control applications. Information from the key on-line instruments should be provided to the plant data system to enable direct control of operational chemistry, and prompt an appropriate action by the operating staff. Data from on-line instruments can only be valid provided the flow of sample to the instrument remains within the required range via proper flow monitoring integrated in the instrument or a flow component in the instrument sample inlet line. Data collection systems must be designed to give positive validation of this condition.

Sample switching or sequencing can be a useful tool when used cautiously. It is important that the sample sequencer be used only for samples that are typically similar in measured value(s), and that the sample times are set long enough to allow for adequate rinse down of the analyzer/sensor between samples. Manual sample switching using manually adjusted valves is discouraged to avoid misunderstanding of which sample is flowing to the instrument. Sample switching should not be used to ignore one sampling point or another during operation.

There are additional requirements for instrumentation on fast start and frequently started plants. One is to have the sample conditioning equipment as close to the source location as possible. Another is that there are advantages for keeping the key instruments (phosphate, silica, conductivity, and CACE) on a continuous refreshing cycle during the shutdown or off-line periods with demineralized water to keep the analyzer working. Continuous refreshing with demineralized water may be effective to keep the instruments ready to measure as fast as possible, but it should be noted that it increases the consumption of reagents, and it may reduce the lifetime of some sensors. It should also be noted that sodium probe sensitivity can be reduced if continuously flushed with high purity water. The highest priorities are for condenser leak detection and ensuring steam purity for turbine admission during the startups.

Off-line analytical techniques (grab samples): Batch or grab samples are collected at predetermined intervals for analysis. The intervals may vary according to the importance and urgency of action required on the basis of the results. The measurements performed off-line may provide confirmation of the validity of on-line results, and may provide additional diagnostic information when key targets are compromised, but they should not provide the key data on which the plant operation is based.

Provision of the Minimum Key Level of Instruments should minimize the perceived requirement to conduct extensive off-line sampling except in the case of deviation from chemistry targets.

3. **On-line Monitoring Techniques**

3.1 Key Instruments

All of the on-line monitoring techniques covered in this section contribute to the matrix of **Minimum Key Instruments** which every plant requires for adequate control of the cycle chemistry. The list is not exclusive of other techniques which may prove valuable in some instances but are not universally essential.

3.1.1 Conductivity (or specific conductivity or direct conductivity)

The conductivity of a dilute aqueous solution such as feedwater, boiler/evaporator water or condensed steam provides an immediate indication of the amount of ionic solutes that are present. It is a non-specific technique, giving the charge carrying capacity of all of the cations and anions that are present. The individual ionic conductivities of all of the common ions are known, and for solutions in which a small number of ions dominate, the conductivity can be correlated with their concentration.

Whenever a fault condition leads to a change in the levels of ionic contamination in a sample there is a resulting change in the conductivity. The technique thus provides a robust, simple but non-specific indicator of the onset of such a fault (e.g., contamination via a condenser leak).

For feedwater, boiler water, steam, and condensate, the dominant ions contributing to the conductivity are likely to be ammonium (or an amine and its decomposition products in some plants) and hydroxide. In the absence of other contaminants, the measured conductivity can be directly correlated with ammonia (or amine) concentration, and for fast start combined cycle units the CACE should be within startup limits within 30 minutes after startup of the gas turbine [2].

For boiler/evaporator water (in drum-type boilers, HRSGs, and once-through boilers in recirculation mode with low load conditions) where minor impurities can accumulate, and further chemical dosing may be applied, the correlation of conductivity with solution composition is subject to more variability. However, the measurement remains valuable for rapid determination of trends in chemical conditions within the boiler/evaporator.

The conductivity of ionic solutions varies with temperature. Ionic mobilities are themselves temperature dependent and, when weak bases (such as ammonia and amines) are present, there is an additional influence of temperature on their dissociation. Commercial instrumentation may compensate for deviation from a reference temperature (normally 25 ºC) to variable degrees of accuracy. However, to minimize errors arising from the differing temperature dependencies of conductivities of the various species that may be present, it is beneficial to adjust the sample temperature to be as close to the reference temperature as practicable.

3.1.2 Conductivity after cation exchange (CACE – Cation conductivity or Acid conductivity)

The online measurement of conductivity after water has passed through a column of strongly acidic cation exchange resin or a cation exchange Electro Deionization (EDI) device that removes cations only is used to indicate the presence of potentially corrosive ionic contaminants. The technique may be referred to as “cation conductivity” or “acid conductivity” in some documentation.

The cation removal eliminates the contribution of ammonium, sodium, and other cations to the conductivity, leaving an acidic solution of the anions that were present. The conductivity of this solution is highly responsive to the presence of strong-acid anions, because of the very high equivalent conductivity of the hydrogen ion. Thus, conductivity after cation exchange is extremely effective for rapidly indicating the onset of cooling water ingress, particularly at seawater cooled sites, and also for detecting contaminated makeup water.

The technique is most frequently applied to the monitoring of condensate, feedwater, and condensed steam. It is also applicable to the monitoring of boiler/evaporator water provided the boiler/HRSG is operating with an All-volatile Treatment or Caustic Treatment.

It can also be used, despite being less directly applicable, for boiler/HRSG evaporator water monitoring in phosphate-dosed plant; in this case the dominant contribution of phosphate ions masks any response arising from contaminant species. Irrespective of the effect of the phosphate ions, it is approximately 3.5 times more sensitive than the direct conductivity measurement to the presence of contaminants such as chloride. However, complete interpretation of the data requires independent knowledge of the phosphate ion concentration.

IAPWS suggests that the normal practice when using cation exchange columns should be to use a cation exchange resin that changes color as it is exhausted. A color change front propagates along the column in service, enabling the operator to judge when replacement by regenerated resin is necessary. The column should be oriented for downwards flow to avoid channelling in the resin column.

Conductivity after cation exchange is also responsive to the presence of anions of weak acids but is subject to the suppression of their effect if the concentration of strong acid anions is sufficient to cause association of the weak acids. An important case is the response to carbonate and bicarbonate from CO_2 contamination of the steam–water circuit. It can be useful to make a measurement of “degassed conductivity after cation exchange” (see Additional Instrumentation) in circumstances where it is necessary to distinguish the presence of potentially more corrosive species in the presence of persistent CO_2 contamination. The IAPWS TGDs on Steam Purity [2] and Air In-Leakage [3] provide guidance on the proper identification of CO_2 ingress, which is of particular importance for fast start and frequently started units. Without knowledge of CO_2, it is not possible to take relaxation for the steam CACE limit, which could hinder the required fast start capability.

For frequently started and fast start units, it is critical that the installed, continuous instrumentation is able to detect condenser leaks at the earliest possible stage so that units can run when required by the local system control. The preferred IAPWS guidance is to monitor at the condensate pump discharge (CPD) as indicated in Section 4.2 and Table 1. It is also recognized that in some plants it is advantageous to include locally conditioned conductivity, CACE, and sodium monitoring in the condenser hot well for fast response especially for seawater cooled units despite having to take a sample against the condenser vacuum.

3.1.3 pH

The pH of a solution is a key parameter in the control of circuit chemistry. The online measurement is made potentiometrically using a pH-sensitive glass membrane electrode and a nominally pH-independent reference electrode. The ISO Standard 105234:2008 "Water quality – determination of pH" [4] and ASTM D-5128 Standard Test Method for On-Line pH Measurement of Water of Low Conductivity [5] apply. The low ionic content of most power plant samples introduces the following specific considerations:

Adsorption of materials onto the surface of the glass electrode or precipitation in the ground glass diaphragm of the reference electrode can cause some errors. More commonly, problems develop because the reference electrode develops some pH dependency which influences the measured potential difference between the electrodes. These errors arise because the reference electrode operates in a relatively concentrated solution of potassium chloride, which is in contact with the much more dilute sample water via a porous ground glass diaphragm. Potassium chloride is chosen because it minimizes the liquid-junction potential across the diaphragm. However, the concentration difference is such that osmosis can cause entry of the sample water into the ground glass diaphragm. Sample solutions with an alkaline pH, such as feedwater and boiler water, can generate significant pH-dependent liquid-junction potentials across the diaphragm, causing a reduction in the measured potential difference between electrodes.

Particular problems arise in the measurement of pH in low conductivity water. pH meters are calibrated against buffer solutions with appreciably higher concentration than feedwater or boiler water samples. The liquid junction effects may be appreciably smaller when the standardizing solutions are in use. The result can be pH readings for feedwater, etc., that are persistently low, often by as much as 0.2 or 0.3 on the pH scale.

Modern high quality instruments address this problem by incorporating measures to minimize the liquid-junction potential. Reference electrodes with free-flowing electrolyte from reservoirs for the reference solution are used to suppress ingress of the sample water into the ground glass diaphragm. The use of a much more dilute reference solution reduces the osmotic effect. It is important that the sample flow rate is stable and constant for pH measurement in high purity water as varying flow rates will influence the stability of the measured value. With very careful attention, it is possible to reduce errors in pH measurement of feedwater and boiler water to less than ±0.05; a more practicable target is to measure pH to within ±0.1 on the pH scale. Regular recalibration, at intervals of no greater than one month, is required to achieve this.

The pH of water depends on temperature. In alkaline solutions, the variability of the dissociation constant of water with temperature must be taken into account. Although commercial pH meters may include temperature compensation facilities, these are based on the temperature dependence of the standard solutions, which are used during calibration. The pH of feedwater, boiler water, and steam will have temperature dependencies that are different from these standard solutions.

The errors arising from these effects are minimized if the sample temperature is adjusted to be as close to the reference temperature (normally 25 ºC) as practicable.

An alternative on-line instrument for the measurement of pH in waters dosed only with ammonia and/or sodium hydroxide relies on a calculation from measurements of the conductivity and the conductivity after cation exchange. This method provides an accurate stable and reliable measurement of pH provided it is used within the range of solution compositions recommended by the instrumentation supplier. Generally, this implies use within the pH range 8.0 to 11.5 and not when contaminant levels exceed the concentration of the alkalizing reagent. During periods of severe deviation from normal chemistry, the potentiometric methods of pH measurement covered above remain accurate whereas the conductimetric method may introduce significant errors.

3.1.4 Dissolved Oxygen

Targets are set for dissolved oxygen concentrations in feedwater for two main reasons. High concentrations of oxygen, when combined with ionic contaminants (particularly chlorides) can yield a risk of under-deposit corrosion (acidic corrosion), which can lead to sudden large scale tube failures in carbon steel evaporators (in high pressure boiler waterwalls and HRSG high pressure evaporators). Very low concentrations of oxygen together with a reducing agent can enable the development of enhanced iron transport and flow-accelerated corrosion in feedwater and in boiler water where all-volatile treatment, AVT, is practiced. Thus, reliable measurement of dissolved oxygen is an essential requirement to ensure that the optimum passive layers are formed throughout the feedwater system.

On-line dissolved oxygen instruments use two distinct techniques: membrane diffusion / amperometric measurement and luminescence-based measurement. In the membrane polarographic or amperometry-technology based instruments, the dissolved oxygen passes through a permeable membrane and is reduced on the electrode creating a measurable electrical current. This current is measured and converted into the concentration of dissolved oxygen. In the luminescence or optical technology-based instruments, the method for dissolved oxygen determination is based on fluorescence and the time that the fluorescence lasts. Dissolved oxygen provides excitation of a chemical component on a sensor spot, which decays under a specific wavelength. The oxygen concentration can be calculated by measuring the decay time of the fluorescence intensity.

Both technologies can be highly reliable and provide accurate readings in typical power system applications. Calibration and maintenance of all types of dissolved oxygen instruments requires extremely careful processes and procedures to achieve accuracy in the low μg/kg (ppb) range typically specified in power cycle operations.

There may, in some instances, be a significant risk of errors in dissolved oxygen measurements derived not from the instruments themselves but from reactions taking place in the sample lines. Any residual reducing agents (oxygen scavengers) or organic breakdown products, etc. may cause reduction of oxygen within the sampling line, resulting in an erroneously low measured value. In changing redox conditions, the walls of the sample line may themselves exhibit some oxygen demand. These difficulties may be minimized by cooling the sample as quickly as practicable (i.e., locating a cooler as close to the sample point as possible), by minimizing sample line length, and by ensuring that sample flow rate is properly maintained. Fittings upstream of a dissolved oxygen analyzer should be as few as possible to minimize the potential for oxygen ingress into the sample.

3.1.5 Sodium

The on-line measurement of sodium ion provides a very sensitive indication of ingress of contaminants to condensate in plants with seawater-cooled condensers and also of the carryover of dosing solutes from boiler drums into steam.

The sensitivity of sodium electrodes may tend to reduce if they are persistently exposed to very high purity water with very low sodium content. Therefore, the instrumentation maintenance schedule must include sodium sensor reactivation and calibration at regular intervals. These processes serve to maintain the responsiveness of the electrode as well as provide an indication of any deterioration.

Glass electrodes sensitive to the presence of sodium ions are used at a controlled high pH. The pH is controlled by addition of an alkalizing reagent into the sample. Diisopropylamine (DIPA) is commonly used. If local regulations or site/plant policy do not allow the use of DIPA, ammonium hydroxide (aqueous ammonia, NH_4OH) can be used. It should be noted that if ammonium hydroxide is used, the ammonia vapor is transferred into the sample, and the reagent volume will decrease only until the ammonia is depleted. Since standard ammonium hydroxide is 30% ammonia by volume, the container should be emptied and refilled whenever the volume decreases by 30%. If high accuracy below 1.0 µg/kg (1 ppb) is required, then the use of DIPA is required.

For fast start and frequently started units, the discussion in Section 3.1.2 on monitoring condensate is equally applicable for sodium, especially for seawater-cooled plants.

3.1.6 Phosphate (only for those drum boilers where a phosphate dosing regime is applied)

The on-line analysis of phosphate using a dedicated instrument requires a higher level of operator care than many of the other key techniques. A colorimetric technique is used in which the sample is mixed with an acidic solution containing ammonium molybdate together with a redox controlling reagent. In the presence of phosphate, a blue compound is generated, and its concentration is detected spectro-photometrically.

The phosphate monitor contains a stock of reagents which must be replenished at regular intervals and may have a peristaltic pump which, from time to time, requires maintenance. Thus, appropriate maintenance schedules are essential for reliable operation of these instruments.

At plants where, for other purposes, regular analyses of boiler water by appropriate chemical techniques, for example ion chromatography, are undertaken, the use of on-line phosphate monitors may not be considered essential.

3.1.7 Oxidation/Reduction Potential (ORP)

The redox condition of feedwater can provide information that is particularly valuable to operators of plants with copper alloys present in the feedwater system. Such plants require reducing feedwater chemistry for optimum operation and this is readily confirmed by ORP measurement. (Note that this technique is only included in the Key Instrumentation set (Table 1) for this group of plants and not for units which have no copper alloys in contact with feedwater.)

The instrument simply measures the electrode potential of an inert surface (generally platinum) against a reference electrode. The measured potential becomes more positive as the balance of species present in the water becomes more oxidizing. Copper alloys in the feedwater corrode at a greater rate and copper (as ions and/or oxide particles) can be released into the circuit when oxidizing conditions exist. Thus, the measurement is used to alert operators to the need to address issues such as air ingress, deficiency in dosing of reducing agents, etc.

3.2 Optional Additional On-line Instruments

In addition to the **Minimum Key Instruments** discussed above, there are a number of **Additional Instruments** which may be deployed with advantage at many plants. The choice of whether to use additional instruments will depend upon factors such as vulnerability of the plant to specific problems such as air ingress, organic contamination of makeup water, presence of silicaceous contaminants in makeup water, etc. Consideration must also be given to the maintenance and calibration requirements to ensure reliability of the data from the additional instruments.

3.2.1 Degassed conductivity after cation exchange (DCACE) (Degassed cation conductivity)

Instrumentation may be used that enables the measurement of conductivity after cation exchange after the most volatile weak acids (particularly carbonic acid) have been removed from solution (generally by boiling or by equilibration with a gas stream). This is most useful for determining the condition of steam (from a condensed sample) since it can be related to the purity criterion for operation of a condensing steam turbine. Particular care is required with temperature compensation or cooling to the reference temperature (25 ºC). Also, the efficiency of removal of volatile weak acids can vary according to details of the technique used.

The technique is not classified within the Key Instrumentation group because it is not required in units that are free of excessive weak acid contamination. Thus, its use is only justified in particularly vulnerable plants.

The IAPWS Technical Guidance Documents (TGD) on Steam Purity [2] and Air In-leakage [3] provide guidance on the proper usage for DCACE, which is of particular importance for frequently started and fast start units. Without knowledge of CO_2 in the cycle, it is not possible to take the relaxation for the CACE normal limit during startup, which could hinder the required fast start capability and on units that do frequent start-up / shut-down cycles.

3.2.2 Silica

Targets may be set for silica in drum boilers providing steam to turbines in order to ensure that the risk of deposition within the turbine is adequately controlled. Since the essential requirement is to meet a target in the steam, it is generally more directly appropriate to measure the silica content of the steam (or in feedwater for once-through boilers). The technique is not classified within the Key Instrumentation group for all plants because units that have been demonstrated to be free of persistent silica contamination may be operated without continuous confirmation of this state (i.e., a limited program of batch analysis may suffice for such plants). The level of maintenance required for on-line silica analyzers is such that it is only justified in particularly vulnerable plants. In such plants, it is preferable to identify the route of silica ingress (frequently the outlet of the makeup water treatment plant) and to monitor this point in order to enable appropriate action to be taken.

Note that some silica in makeup water may be present in non-reactive form. This has implications for analysis and can hinder the identification of the source of the contaminant. Hydrolysis of non-reactive silica at higher temperatures can then yield reactive silica in boiler water and steam.

The measurement of silica uses a colorimetric technique in which the sample is mixed with ammonium molybdate at a controlled low pH to form yellow molybdosilicic acid which is subsequently reduced to a heteropoly blue complex that can be detected spectrophotometrically.

Non-reactive silica in makeup water cannot be analyzed with the colorimetric technique (neither for on-line instrumentation nor in the laboratory from grab samples). It requires an off-line analysis, as non-reactive silica must be converted into the reactive form by heating with alkali before the colorimetric analysis.

Silica analyzers may be deployed as multichannel instruments, with the capability to switch between multiple samples.

Appropriate maintenance schedules are required to ensure replenishment of reagents, to check operation of pumping and mixing systems, and to recalibrate.

3.2.3 Total Organic Carbon

The presence of organic materials in makeup water and return condensate can have a detrimental influence on makeup water treatment plant operation. Some organic materials reaching the steam–water circuit may cause the formation of deposits that impact on heat transfer and may generate potentially corrosive degradation products.

Measurement of general levels of organic contaminants is achieved by oxidation to carbon dioxide. The total organic carbon, TOC, is then quantified from the resultant increase in carbon dioxide. The technique is non-specific, providing no definitive information on the nature or source of the organic materials present.

4. Circuit Locations for On-line Monitoring

This document covers the requirements for monitoring of a wide range of steam/water circuits of generating and equivalent plants. The range includes drum, subcritical, and supercritical once-through boilers in conventional fossil-fired plants together with the heat recovery steam generators (HRSG) of combined cycle plants. In combined cycles, the inclusion of multiple pressure circuits will, in some cases, introduce complexities, particularly where low pressure systems operate, in part, as feed circuits for higher pressure systems. Fast start and frequently started units will also need some additional instrumentation as outlined in the previous section. The scope of coverage also includes some cogeneration and industrial plants in which part or all of the condensate may derive from steam used in an application that is external to the main circuit. This can introduce additional requirements for monitoring, preferably at the condensate return stream before entering the main condensate circuit, especially in the cases where contamination of return condensate cannot be excluded.

In all cases, it is essential to ensure adequacy and reliability of sample extraction, conditioning, and delivery to the instruments. This is discussed in the IAPWS TGD on corrosion product sampling and analysis [6].

It is emphasized again that this is an IAPWS Technical Guidance Document and that, depending on the requirements, the use of simpler instrumentation may be adequate, or more complex techniques and instrumentation may be necessary when specific issues arise.

4.1 Makeup Water

All steam generating circuits require a source of makeup water to balance losses via boiler blowdown systems, etc. The makeup water flow will, in most circuits, be a small proportion of the steam generation rate, but in some co-generation applications it may be much larger (up to 100% in cases of zero returned condensate). In the latter cases, there may be additional requirements for monitoring to confirm purity.

The purity of makeup water is critical. It is necessary to consider both newly purified water at the makeup water treatment plant outlet and stored condensate which may contain some dosed ammonia or amine and, potentially, some undesirable contaminants.

> For demineralized water, the **Minimum Key Level** requirement is measurement of **conductivity** upstream of the point of mixing with dosed condensate.
>
> For condensate from a storage tank open to atmosphere (vented), the **Minimum Key Level** requirement is measurement of **conductivity after cation exchange** upstream of the point of delivery of the water into the main circuit.
>
> For units with a history of silica accumulation, the deployment of a **silica** monitor will be justified (note the comments on non-reactive silica in section 3.2.2).
>
> For units with a history of organic contamination of makeup water, the measurement of total organic carbon, **TOC**, may be justified.

4.2 Condensate

Monitoring of condensate (usually at the condensate extraction pump discharge, CPD) is essential in all plants to provide the first warning of ingress of contaminants as a result of condenser leakage, regenerant chemicals from the makeup plant, or contaminated condensate from a storage system. This location also provides an indication of air in-leakage. The point of measurement is normally the CPD because of the requirement for pressure in the sample line to be greater than atmospheric pressure. It is emphasized that locating the analyzers as close as possible to the sample extraction point is most important to assist in early detection for frequently started and fast start units, especially for seawater-cooled plants. In Section 3.1.2, the possibility of adding an additional monitoring package (CACE, sodium, and conductivity) in the hotwell was discussed for these plants despite having to take a sample against the condenser vacuum. Probably the most useful additional measurement in the condensate for fast start units would be DCACE, because together with the other parameters measured at the CPD it will give fast information on whether there is air in-leakage or a more problematic mode of contaminant ingress taking place.

The following instruments should be included as **Key Instrumentation** at the CPD:

Conductivity after cation exchange is the most important parameter at this point because it rapidly alerts the operator to ingress of potentially corrosive anions.

Sodium measurement is particularly valuable in plants cooled by saline waters, particularly if there is a high risk of condenser leakage and there is no provision for condensate polishing. It offers higher sensitivity than conductivity after cation exchange. Consequently, while small leaks may be extremely difficult to locate and eliminate, their detection and escalation is most readily monitored by sodium measurement. (Optional, but strongly recommended, for plants on freshwater-cooled sites and not necessary for plants with air-cooled condensers).

Dissolved oxygen measurement can provide a valuable indication of air ingress rate and of oxygen entering into the high pressure part of the cycle.

The following **Optional Additional Instruments** may be included at the CPD:

Conductivity and **pH** are not always measured but can provide useful confirmatory information.

In plants that are vulnerable to high air ingress rates or to the presence of carbonate as a result of oxidation of organic impurities, the measurement of **degassed conductivity after cation exchange (DCACE)** can provide useful additional information. This is also useful for fast start and frequently started units.

Proxy methods for the monitoring of corrosion products. IAPWS is currently developing a new TGD for continuously monitoring iron and copper corrosion products using **Turbidity** and/or **Particle Measurements** [7].

When steam is used in an application external to the main water/steam circuit (as in cogeneration plants, supplying steam to industrial plants or to district heating networks), the monitoring of the condensate return stream, at least by CACE, can provide early warning of ingress of contaminants, due to leakage in heat exchangers of the external application.

4.3 Feedwater

In fossil-fired plants, feedwater composition is normally monitored at the economizer inlet, EI. This point is downstream of the low pressure feed heaters, deaerator, and high pressure feed heaters. Combined cycle plants do not have all of these feed heaters and the appropriate sampling points will usually be downstream of the feed pumps; however, in some modern plants a sampling location upstream of the pumps is chosen to reduce the pressure-related safety requirements. For those low pressure circuits where the drum operates at pressure derived from the condensate extraction pump, the sample from the CPD is appropriate.

For units with condensate polishing systems, it is necessary to provide additional dedicated monitoring at the condensate polisher outlet, CPO. Careful consideration of the circuit configuration is necessary, particularly when there are multiple parallel paths, in order to ensure that the instrumentation warns the operators to take appropriate action.

4.3.1 Plants with condensate polishers (Measurement at Condensate Polisher Outlet, CPO)

The following instruments should be included as **Key Instrumentation** at the CPO:

Conductivity after cation exchange at CPO is the most important parameter because it rapidly alerts the operator to ingress of potentially corrosive anions and is more sensitive than conductivity.

Sodium at CPO rapidly alerts the operator to cation breakthrough and hence to the need for regeneration of the resins. In this context it is more sensitive than conductivity. For plants operating with condensate polishers in the ammonium form, the addition of sodium monitoring at CPO will ensure protection from contamination of feedwater by residual regenerant.

A sample is taken from the polishing plant outlet (each bed in the case of parallel streams), upstream of subsequent dosing.

Additional Instrumentation:

Conductivity measurement at CPO is valuable to provide confirmation of the effective operation of the polisher and to alert the operators to the need for regeneration of the resins.

4.3.2 All Plants (with or without condensate polishers) (Economizer Inlet, EI, on conventional plants, and downstream of the feed pumps on HRSG plants)

The following instruments should be included as **Key Instrumentation**:

Conductivity measurement at EI is essential to give a rapid indication of the successful operation of dosing systems to control feedwater pH. This is conventionally measured at these locations.

Conductivity after cation exchange is also monitored at these locations in order to confirm that no contaminants have entered the feedwater with the dosed alkali (ammonia or amine), through condenser leakage or via any other route.

pH measurement (or assessment from conductivity and conductivity after cation exchange) provides further confirmatory information that the dosing regime specified for the plant is being achieved.

Dissolved oxygen is measured to confirm its satisfactory control within the target regime for the plant. In those units where oxygen dosing to the feedwater is practiced, it is essential to confirm that the target range is being achieved at the economizer inlet. Although it is common practice to use a single instrument to monitor a number of locations, a dedicated instrument will be required in circuits where the dissolved oxygen concentration is closely controlled.

ORP measurement at deaerator inlet, DAI, or in the absence of a deaerator at EI is used to provide valuable information for the operators of a plant that has copper alloys present in the feedwater heaters. (Note that this technique is only included in the Key Instrumentation set for this group of plants with copper alloys.)

The following **Optional Additional Instruments** may be included for feedwater monitoring:

Dissolved oxygen may be measured upstream and downstream of the deaerator to confirm its satisfactory operation. The use of a single instrument switched manually between two or more sample points may be appropriate, and where a high degree of confidence in deaerator performance has been achieved further regular measurements may not be justified. The comments on switching in Section 2 should be noted.

Proxy methods for the monitoring of corrosion products. IAPWS is currently developing a new TGD for continuously monitoring iron and copper corrosion products using **Turbidity** and/or **Particle Measurements** [7].

4.4 Drum Boiler Water/HRSG Evaporator Water

The detailed requirements for monitoring boiler drum waters vary according to the chemical regime in use.

Ideally, samples are taken from appropriately designed sampling probes in the boiler downcomers. However, it is common to find samples taken from the boiler blowdown lines. This practice is really only satisfactory if flow in the blowdown line is continuous. It inhibits the option of operating the plant without blowdown when contaminant ingress rates are low.

The choice of the downcomer sample point location is particularly important for drum boilers operating with oxygenated chemistry regimes.

4.4.1 Drum boiler plants with AVT (no solid alkali being added to the drum)

This section is applicable to the drums on conventional fossil plants and on combined cycle/HRSG plants.

The use of all-volatile treatment, AVT, implies very rigid restrictions on contamination levels in the boiler.

The following instruments should be included in the **Minimum Key Level:**

Conductivity measurement is valuable to provide a warning of deviation from the normal operation of the boiler. In sliding pressure operation, it must be recognized that volatile dosing agents will favor the steam more strongly as pressure falls and thus the equilibrium state of the boiler dosing will be pressure dependent.

Conductivity after cation exchange is monitored in order to confirm that no contaminants are accumulating to an excessive level in the boiler water and to guide the operators on the adjustment of blowdown rates.

pH measurement provides further confirmatory information that the dosing regime specified for the plant is being achieved.

The following **Optional Additional Instruments** may be included for drum water monitoring under AVT chemistries.

Silica may be measured in the boiler water if the relationship between its concentrations in water and steam are known. (Although the aim is to control silica levels in steam, the measurement in boiler water may be more reliable in some circumstances.) Note, however, that the relationship between silica in drum water and in steam may change according to load, pressure, drum water level, condition of drum furniture, etc. so the concentration in steam remains the Key Measurement.

4.4.2 Drum boiler plants with phosphate treatment

This section is applicable to the drums on conventional fossil plants and on combined cycle/HRSG plants when phosphate is the treatment of choice. Phosphate chemistry may be rather complex in a practical boiler with other contaminants present and with the risk of phosphate hideout processes occurring. A full description of the boiler chemistry cannot be attained without comprehensive analysis of the concentrations of sodium, phosphate, and all of the other ionic species that may be present at significant concentrations (chloride, sulfate, carbonate, ammonium, etc.). A pragmatic approach is normally essential.

The following instruments should be included in the **Minimum Key Level**.

> **Conductivity** measurement again provides a warning of deviation from the normal operation of the boiler. In boilers where high levels of phosphate hideout occur, there can be large increases in conductivity during periods of low load operation.
>
> **Conductivity after cation exchange** is of some value in this dosing regime despite the complicating factor that results from the contribution of the phosphate anion. When potentially corrosive contaminants such as chloride are present, the conductivity after cation exchange rises appreciably more rapidly than the conductivity. However, it is acknowledged that measurements of conductivity and conductivity after cation exchange without additional information on phosphate and contaminant ion concentrations cannot yield a full and unambiguous understanding of the behavior of the boiler water. Complete interpretation of the measurement requires, at a minimum, knowledge of pH, and is simplified by knowledge of the phosphate concentration.
>
> The use of cation membrane electric dialysis to reduce the maintenance requirements for cation exchange resin when analyzing boiler waters can be beneficial. Such techniques may be expected to find more widespread use in the future.
>
> **pH** measurement is valuable because it demonstrates that the phosphate present in the boiler water is appropriate to provide the necessary control over the risks of both acidic and alkaline corrosion. At low phosphate concentrations, the measured pH at 25 ºC can be significantly influenced by the ammonia concentration. Note, however, that at higher phosphate concentrations, small condenser leaks may have only a very minor effect on the pH of the bulk boiler water. Thus, pH measurement alone is an insensitive indicator of corrosion risk in phosphate-dosed boilers.
>
> **Phosphate** measurement is necessary to enable unambiguous control of dosing in boilers that are subject to hide-out and to allow the interpretation of the conductivity after cation exchange in terms of other contaminants. However, given the costs and the level of operator care required for the reliable use of on-line phosphate monitors, many plants that have no problems with phosphate ion control (hide-out, etc.) may operate satisfactorily without this instrumentation.

The following **Optional Additional Instruments** may be included for drum water monitoring under phosphate dosing conditions.

> In circumstances where it is necessary to achieve a fuller understanding of the boiler chemistry (specifically the [sodium]:[phosphate] molar ratio which can be strongly related to corrosion risk), it becomes essential to monitor **sodium** as well as phosphate concentrations. Complete understanding of phosphate chemistry in drum boilers requires a high level of attention to the analytical techniques by the plant chemist or an appropriate specialist.

Silica may be measured in the boiler water if the relationship between its concentrations in water and steam are known. (Although the aim is to control silica levels in steam, the measurement in boiler water may be more reliable in some circumstances.)

4.4.3 Drum boiler plants with caustic treatment

This section is applicable to the drums on conventional fossil plants and on combined cycle/HRSG plants when NaOH is the alkalizing treatment of choice.

The monitoring of sodium hydroxide dosing regimes in drum boilers is generally simpler than the phosphate case, but it is essential to include measures to alert operators to any over-dosing, which can itself carry a corrosion risk for the boiler waterwalls and also for the steam turbine (by carryover).

The following instruments should be included in the **Minimum Key Level**:

Conductivity measurement generally provides a direct indication of the dosed concentration of sodium hydroxide. Its measurement can be used as a key parameter in the adjustment of boiler blowdown rates and dosing system setting.

Conductivity after cation exchange gives a clear indication of the accumulation of impurity anions in the boiler water and therefore provides additional information on which to base control of the blowdown system.

pH measurement provides confirmatory information that the target dosing regime is being achieved.

The following **Optional Additional Instruments** may be included for drum water monitoring under sodium hydroxide dosing conditions.

Silica may be measured in the boiler water if the relationship between its concentrations in water and steam are known. (Although the aim is to control silica levels in steam, the measurement in boiler water may be more reliable in some circumstances.) Note that silica is less volatile in boilers with caustic dosing than in AVT dosed units.

4.5 Once-through Boilers

Once-through boilers require treatment exclusively with volatile dosants in order to eliminate the risk of added chemicals concentrating at dry-out. Regimes may be reducing (conventional AVT, AVT(R)), oxidizing (conventional AVT, AVT(O)), or oxygenated (OT). Both conventional subcritical and supercritical plants and combined cycle/HRSG plants with once-through boilers are covered.

The main monitoring requirements for once-through boilers are covered in the feedwater section above.

> The use of steam separator vessels provides an opportunity for monitoring any potential accumulation of contaminants at dry-out on the evaporator tube surfaces. Measurement of **conductivity** and **conductivity after cation exchange** of water sampled from the separator vessel drain can provide a valuable warning of ingress of contaminants to the circuit.

If Benson boilers are operated in recirculation mode, impurities accumulate in the boiler separator water (boiler separator drains) in the same way as in drum boilers. By monitoring the boiler water conductivity, discharge of boiler water can be controlled and regulated to limit the accumulation.

4.6 Steam

This section is applicable to drum boilers on conventional fossil plants, combined cycle/HRSG plants, industrial plants, and to once-through units.

In drum boilers, the steam may be sampled at two locations:

> The first is upstream of superheaters; saturated steam in this part of the plant may contain entrained water droplets and this requires specific consideration of sampling probe design.
>
> The second is downstream of the superheaters; superheated and reheated steam is free of droplets and may contain solutes derived from attemporator sprays. The sample cooling requirements are more arduous for the superheated steam.

In once-through boilers, superheated and/or reheated steam sampling are the only practicable options.

Steam is monitored to ensure adequate purity, free from excessive carryover of boiler constituents (drum boilers only), free from constituents derived from contaminated spray water, and free from unacceptable concentrations of silica that could form deposits in turbines.

Steam Purity is discussed in an IAPWS TGD [2].

The following instruments should be included in the **Minimum Key Level**.

4.6.1 Saturated Steam

> Provided that appropriately designed sampling probes are in place, the monitoring of **sodium** concentration and **conductivity after cation exchange** provides information on the risk of carryover of constituents from the boiler into the steam turbine. Targets may be set for both parameters and operational changes may be required in order to ensure compliance. Persistent elevated values may indicate mechanical damage within the boiler drum.

In many plants, good control over the risk of carryover is consistently achieved and operators may wish to reduce the saturated steam monitoring level. Where comprehensive monitoring of superheated or reheated steam is practiced, the monitoring of saturated steam may be reduced to the level recommended in the IAPWS Technical Guidance Document on Carryover [8].

However, the risk of deterioration of steam purity does not diminish over the lifetime of the plant. It may result from a number of causes, and therefore complete suspension of all steam monitoring is not recommended.

Technically, superheated steam or reheat steam is preferred to saturated steam for continuous on-line monitoring. However, as indicated in the parallel IAPWS Technical Guidance Document on Carryover [8], the saturated steam location may be used to record carryover on a frequent, but non-continuous basis.

4.6.2 Main Steam and Reheat Steam

Targets for superheated and reheated steam may be more directly related to the conditions that are acceptable within the steam turbine. Some deposition within superheaters and reheaters can result in a short-term reduction of concentration of non-volatile contaminants but, during prolonged operation at steady load, equilibrium will become established.

The sampling point may be at the superheater outlet or at the reheater outlet upstream of the turbine bypass system to enable operators to check steam purity before the turbine is released for operation. The reheater outlet provides information on steam purity downstream of all locations where feedwater is added to steam (attemperators), and therefore provides data that are responsive to any contamination of the spray water. However, additional deposition of solutes that have low solubility in steam occurs at the lower pressure in reheaters and this can prejudice the results.

The following instruments should be included in the **Minimum Key Level** at the Main and Reheat Steam:

> The monitoring of **sodium** concentration and **conductivity after cation exchange** provides information on the risk of carryover of solutes from the boiler and of contaminants from spray water into the steam turbine. Targets may be set for both parameters and operational changes may be required in order to ensure compliance. Persistent elevated values may indicate mechanical damage within the boiler drum or feedwater contamination. Both circumstances require operator intervention to identify and mitigate the problem.
>
> The monitoring of **silica** concentration provides assurance that the plant can be operated with adequate control of the risk of silica deposition in steam turbines. In those plants where the make-up water contains non-reactive silica, monitoring of the main steam may provide the most reliable information on the need for remedial actions.

The following **Optional Additional Instrument** may be included in the Main and Reheat Steam:

> In plants that are frequently started and for fast start combined cycle plants, the measurement of **degassed conductivity after cation exchange (DCACE)** can provide useful additional information to distinguish air in-leakage from other forms of contaminant ingress such that a relaxation in CACE associated with the former can be determined to prevent delay in starting a unit [2].

4.7 Fast Start Units

This section is applicable to combined cycle/HRSG plants that need to return to service quickly and is a summary of items covered in other sections of this IAPWS Technical Guidance Document. The emphasis for these units is to reduce the time to acquire correct and representative analyses [9, 10] and to identify any chemistry issues as soon as possible so that the chemistry does not restrict the required short time for return to service. Therefore, particular attention should be put on minimizing sample travel time between extraction points and monitoring equipment by ensuring suitable line sizing, routing, and lengths, in particular for samples and measurements that are critical during the startup phase. Additionally, automatic flushing water for the critical analyzers (Section 2) is recommended. To provide additional clarification between contamination and air in-leakage during startup, DCACE in the condensate (Section 4.2) and on superheated steam will be of additional benefit [11].

5. Off-line Batch (grab) and Confirmatory Analyses

It will be necessary on occasion to perform additional off-line analyses to confirm satisfactory plant operation or to diagnose the causes of deviations from targets. It is important to note that if a plant has the Minimum Key Level of Instrumentation there is no absolute requirement for operators to conduct a frequent grab sampling matrix of parameters to “check” on-line instruments.

Under the direction of the Plant Chemist or supervisor responsible for chemistry, grab sampling should be conducted whenever it is required for troubleshooting or when contaminant enters the cycle as indicated by the Minimum Level of Instrumentation.

Additional collection and analysis of grab samples on a periodic basis during prolonged periods of normal operation within guideline targets will reinforce plant operation by ensuring that appropriate procedures are in place and that operating/chemistry staff retain familiarity with them.

The techniques that can be deployed are many and varied. They should be matched to the specific application.

Iron. Monitoring total iron (soluble plus particulate) concentrations provides assurance that the rate of transport of corrosion products into the boilers and onto steam turbine blading is kept within acceptable limits. It also can demonstrate whether the steam/water circuit is potentially experiencing flow-accelerated corrosion (FAC). The techniques used must be capable of detecting iron at concentrations of 1 to 5 μg/kg and of quantification of iron at much higher concentrations. The IAPWS TGD on Corrosion Product Sampling and Analysis [6] provides the needed information.

Copper. Many older plants have copper alloys in condensers and in feedwater heaters. Copper can readily be oxidized into a mobile form and can subsequently deposit within evaporator tubes or, in a high pressure plant, on steam turbines. Analysis of feedwater can be used to establish whether effective control over copper transport is being achieved. The

IAPWS TGD on Corrosion Product Sampling and Analysis [6] provides the needed information.

Ionic Contaminants. When it becomes necessary to identify the source of contaminants in the steam–water circuit that are responsible for increases in conductivity (direct or after cation exchange), the use of ion chromatography can provide particularly valuable information. By appropriate choice of analysis columns and eluents, it is possible to identify and quantify a wide range of cations and anions (including organic acid anions).

6. References

1. IUPAC, *Quantities, Units and Symbols in Physical Chemistry* (RSC Publishing, 2007).
2. IAPWS, IAPWS TGD5-13, *Technical Guidance Document: Steam Purity for Turbine Operation* (2013), available from http://www.iapws.org/techguide/Purity.html.
3. IAPWS, IAPWS TGD9-18, *Technical Guidance Document: Air In-Leakage in Steam-Water Cycles* (2018), available from http://www.iapws.org/techguide/AIL.html.
4. ISO Standard 105234:2008. *Water quality – determination of pH.*
5. ASTM D5128:2014, *Standard Test Method for On-Line pH Measurement of Water of Low Conductivity*.
6. IAPWS, IAPWS TGD6-13(2014), *Technical Guidance Document: Corrosion Product Sampling and Analysis for Fossil and Combined Cycle Plants* (2014), available from http://www.iapws.org/techguide/CorrosionSampling.html.
7. IAPWS Power Cycle Chemistry Working Group, White Paper PCC WP 24-001, *Corrosion Product Sampling, Monitoring and Analysis for Flexible and Fast Starting Plants* (2024). Available from https://www.iapws.org/wg/PCC.html.
8. IAPWS, IAPWS TGD1-08, *Technical Guidance Document: Procedures for the Measurement of Carryover of Boiler Water into Steam* (2008), available from http://www.iapws.org/techguide/Carryover.html.
9. Rziha, M., and Wuhrmann, P., Cation Conductivity Monitoring during Startup, *PowerPlant Chemistry* **9**, 644-648 (2007).
10. Sollner, A., Rziha, M., and Wuhrmann, P., *Optimization of Sampling System for Faster Start-up of Cycling Power Plants*, VGB PowerTech 03/2010, 59-63.
11. Clark, P.J., Effects of Steam Sample Degassing on CCGT Station Startup Profile, *PowerPlant Chemistry* **12**, 246-251 (2010).

Table 1 Summary of Minimum Key Instrumentation Requirements.

A range of additional optional instrumentation may be required on plants which have non-generic problems. Their use, as covered in the text above, will be plant-specific and subject to local considerations.

Sampling location		Minimum Key Instrumentation	Caveat
Condensate Pump Discharge (CPD)		Conductivity after cation exchange	
		Dissolved oxygen	
		Sodium (Key on seawater-cooled plants)	Not plants with air-cooled condensers
		DCACE	Frequently started and fast start plants.
Feedwater (Drum and Once-through boiler circuits)	Condensate Polisher Outlet (CPO)	Conductivity (CACE if CPP is operated in ammonia form)	
		Sodium (Key Instrument if CPP is operated in ammonia form)	
	Economizer Inlet (EI) or main feed pump (HRSGs)	Conductivity	
		Conductivity after cation exchange	
		pH	Can be calculated.
		Dissolved oxygen	
	Deaerator inlet	ORP	Plants with copper alloys in feedwater circuit.
Boiler drum Downcomer (preferable) or blowdown	Plants on AVT and those on Caustic treatment	Conductivity	
		Conductivity after cation exchange	
		pH	
	Plants on OT	Conductivity	Sample should be from downcomer.
		Conductivity after cation exchange	
		pH	
		Dissolved Oxygen	

Sampling location		Minimum Key Instrumentation	Caveat
	Plants on phosphate treatment	Conductivity	[Na]:[PO_4] molar ratio measurement may require additional monitoring.
		Conductivity after cation exchange	
		pH	
		Phosphate (plants that prove vulnerable to hide-out or to other issues with phosphate concentration control)	Data interpretation based on conductivity and CACE measurements alone may be ambiguous.
Steam	Saturated	Conductivity after cation exchange	Iso-kinetic sampling is necessary.
		Sodium	
	Superheated/ Reheated	Conductivity after cation exchange	
		Sodium	
		Silica	For plants that have consistently demonstrated a low risk of elevated silica concentrations in steam, the continuous monitoring may be considered nonessential.
		Degassed CACE	Frequently started and fast start plants.
Make-up water into water/steam cycle		Conductivity	
		DCACE	Plants with storage tank exposed to atmosphere.
		Silica	Plants where there is a risk of non-reactive silica or organic contamination of raw water.
		Total Carbon	