Memorandum

Large and ASSOCIATES

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From:	John H Large	19 October 2016
Cc:	********, *********	
SUBJECT:	**BEZNAU UNITS 1 AND 2 – STEAM GENERATOR REPLACEMENTS**	

Steam generator (SG) replacements were undertaken at Beznau Unit 1 in 1993 and at Unit 2 in 1999. Originally Westinghouse 2-loop pressurised water reactors (PWR), the replacement SGs were manufactured and fabricated by Framatome with the major components in forged steel from the le Creusot Forge now (since 2006) in the ownership of French nuclear design and construction company AREVA.

Also, it is believed that the Leibstadt nuclear power plant (NPP) may have components supplied from the Creusot Forge, although these are not subject of this note.

STEAM GENERATOR: A SG is a vertical heat exchanger comprising two separate circuits that transfer heat from the reactor primary circuit coolant to a separate steamraising circuit that feeds to and powers the turbo-alternators.

The reactor coolant circuit delivers hot water to the primary side of the *bottom channel head* located at the base of the SG. The primary water is then routed to 3,000 to 7,000 small diameter (~20mm), thin-walled tubes that are peened into the *tubesheet*, rising in a U-shaped bundle through about two-thirds the height of the SG to return to the 'cold' side of the divided *bottom channel head* that diverts to the reactor primary circuit to be continuously pumped back through the reactor fuel core for reheating.

The separate secondary steamraising side or shell of the SG is the jacket formed of *annular rings* or *shells* that enclose the primary tube bundle, receiving water pumped from the turbine condenser, steam is raised in the jacket to be passed to the turbines from an outlet provided at the top of the SG by the *elliptical top dome*.

A typical SG is about 20m tall, 3 to 4m diameter and weighs of the order of 300 to 400 tonnes. The larger SG components (*heads*, *tubesheets*, *domes* and *shells*) are upset forged either directly from a cast ingot or hot formed from a previously cast slab or plate of steel.

REPLACEMENT STEAM GENERATORS: Replacement of the SG becomes justified when the number of tube failures (which are individually isolated by plugging) reaches 7% to 12%, thereby degrading the thermal output and electricity generating capacity of the nuclear power plant (NPP). The *bottom channel head*, *tubesheet* and tube bundle form part of the boundary of the reactor primary coolant circuit and must be safeguarded against major failure at all times.

Generally, underlying individual tube failure and the overall tube failure rate is the service age of the NPP, with both overall and rate of tube failure reaching unacceptable levels typically in the third decade of individual NPP operation. Thus, following the high rates of new PWR NPP construction and commissioning in the 1970s and 80s, the demand for replacement SGs (RSGs) rose during the 1990s and extended through to present times. For example, France commenced its 1st phase RSG programme in the early 1990s involving 20 or more of the 900MWe series of three-loop NPPs or about 60 RSGs in total, completing this programme in around 2008. Then, from 2011 France embarked upon its present 2nd phase RSG programme, ordering a total of 44 RSGs comprised 12 sourced from Westinghouse and 32 from AREVA using Creusot and, possibly, Japanese forges for the RSG main components – these RSGs are presently under manufacturer, although delayed because of manufacturing quality issues, particularly at the AREVA Creusot forge.

Similar RSG programmes occurred and are carrying on throughout the worldwide nuclear industry, so much so that meeting this demand for the RSG *head*, *tubesheet*, *elliptical dome* and *annular shell* heavy steel forgings is challenging. Suppliers of RSG, such as Westinghouse and AREVA, now tend to sidestep the demand-supply difficulties by ordering various component parts from different sources as capacity permits, resulting in a single RSG that might comprise components sourced from a mix of forges on a worldwide basis.

Without access to the individual component part records it is not possible to reliably trace the lineage or provenance of any one RSG – this can lead to difficulties in establishing supply chain patterns should flaws arise in a particular component or the RSG assemblage overall.

CARBON ANOMALY AND IRREGULARITIES: Recently, LargeAssociates reported on the so-called *carbon anomaly* and *irregularities* of heavy forged steel components sourced from, in particular, le Creusot Forge and from the overseas suppliers, particularly, the *Japan Casting and Forging Company* (JCFC) and *Japan Steel Works* (JSW). It is believed that component flaws and shortfalls in material characteristics, particularly toughness, possibly entered the French nuclear supply chain from as early as 1965 and, moreover, it is now firmly established that flawed components, particularly from the 1st phase replacement SG programme in France through the 1990s, were installed and remain in French operational NPPs.

Of interest here is that of the 18 French NPPs identified for further investigation in mid-2016, 4 have been permitted to return to power unconditionally, 6 were allowed to return to power but subject to further investigation and evaluation and, it is believed, *'compensatory'* measures necessary to mitigate the risk of fuel melt incident; and 8 remain in enforced outage whilst further examination and evaluation is undertaken by the operator EdF. However, on 18 October following receipt of non-destructive examination (NDE) results taken at the SGs installed in Tricastin 1 and Tricastin 3 NPPs, the French nuclear safety regulator *Autorité de Sûreté Nucléaire* (ASN) shutdown a further 5 NPPs so that, other than St Laurent 1, all NPPs with JCFC SG components are now withdrawn from operation and will not be permitted to resume power operation without the spectres consent of ASN.

All of the NPPs presently in enforced outage or under conditional operation (St Laurent) have suspect SG *bottom channel head* components with the presence of positive macrosegregation zones (ie locally excess carbon and reduced material toughness) – the flawed bottom *channel head* components are known to have been sourced from JCFC. The NDE results from the Tricastin 1 and 3 NPPs reveal excess carbon content levels in the diversely stress manifold (nozzle) area reaching about 200% of the permitted levels that have raised issues relating to how such heavily flawed components could have entered the French nuclear supply chain without detection.

In addition, these and a number of other French NPPs are under investigation with SG deficiencies, including a steam generator with an excess carbon zone in the lower annular ring (Fessenheim 2); and with installed JSW- and Creusot-sourced *tubesheet* and *elliptical dome* components also being shown to be at-risk. Each of the held over French NPPs were subject to the French 1st phase RSG programme implemented from the mid-1990s through to 2009 or thereabouts, that is the same period during which the Beznau Unit 1 (1993) and Unit 2 (1999) replacement SGs took place.

RELATIVE TO BEZNAU UNITS 1 AND 2: So far as Beznau relates, the point here is that flawed components (irrespective of the manufacturing source) under the control of AREVA were able to enter the French nuclear supply chain, be installed and commissioned in operational French NPPs without detection by ASN.

So it follows, RSGs destined for installation at Beznau 1 and 2, also supplied by AREVA but subject to scrutiny of Eidgenössisches *Nuklearsicherheitsinspektorat* (ENSI), must also be at risk of having entered the Swiss nuclear supply chain in a flawed condition – there is no reason to believe that ENSI is any more informed or exacting in its regulatory role than its French Counterpart ASN.

A second point is that ASN has declared that it has no regularity responsibility for nuclear components contracted by AREVA for installation in overseas NPPs and, moreover, the ASN investigations to date have pointedly sidestepped involvement in any issues involving AREVA's dealings with overseas NPPs. Indeed, the examination of the *Qualification Technique* (QT) files to date as reported by AREVA, which has exposed 87 *'irregularities'* in the Creusot manufacturing routes, seems to have been exclusive to French NPP components.

It is now generally understood that AREVA is to extend this 1st round scrutiny of the Creusot QT procedures to the detailed examination and/or re-examination of a further 9,000 or so files suggesting, or so it seems, that AREVA's first examination was not particularly exhausting and that there are more irregularities in the French nuclear supply chain to be discovered.

Whereas examination across such a large number of records might be expected to reveal a pattern of flaws, omissions, or the like to ASN, thereby enabling it to better understand and, perhaps, mitigate the risk to French NPPs, there is no irrefutable duty on its or AREVA's part to inform ENSI of such. In this respect, ENSI might be at considerable disadvantage if it were only afforded access to those files and QT records that related specifically to the Beznau Units 1 and 2 RSGs.

Also, it is worthwhile setting the comparison between the regulatory powers excisable by ENSI and ASN respectively: On its part ASN has, effectively, the power of the State so it can order AREVA and the French NPP operator *Électricité de France SA* (EdF) to make files and records accessible; it can require tests and analysis to be conducted; and it can, has it has already done for the Flamanville 3 components, prioritise and effectively marshal AREVA's resources into first addressing issues that are of prime interest to the French State. On its part, since ENSI has no direct powers or contractual ties over AREVA it cannot order retesting and analysis so, it is assumed, ENSI must rely upon goodwill arising from any residual contractual obligations that AREVA holds with the Beznau NPP operator *Axpo Holding AG* (previously *Nordostschweizerische Kraftwerke NOK*).

ENSI'S RESPONSE TO GREENPEACE CH ENQUIRIES: When asked if and how the Beznau Units 1 and 2 RSGs could be stated to be free of positive macrosegregation and the accompanying excess carbon content at a micro-scale and, similarly, free of irregularities linked to the Creusot manufacturing route, ENSI responded (bulleted thus ○ - translated from German). ENSI's response is not particularly informative nor comprehensive, so much so that it would be useful to request further and more specific information, as follows:-

- ○ *The RSGs of Units 1 and 2 were installed in 1993 and 1999 respectively - the four SGs come from le Creusot Forge*

  First, it would be useful to determine the design code stipulated by ENSI for the pressurized equipment of the reactor primary cooling circuit - the suggested request for further information (bulleted thus •) to ENSI might be something along the lines:-

  - Please state the pressure vessel design and construction code for Class 1 (N1) equipment of the reactor primary coolant circuit stipulated by ENSI for the Beznau replacement SGs – for example ASME III BPVC, RCC-M or otherwise – and state if any domestic (Swiss) provisions are imposed in addition to the basic design and construction code.
  - Please state if there occurred any change/amendment to the above codified requirements on the transition from HSK to ENSI in or about 2009.

  The sourcing of each of the critical N1 components should be verified by ENSI:-

  - Please confirm, or otherwise, that each of the following SG components was manufactured by upset forging of cast ingot blanks – i) *bottom channel head*, ii) *tubesheet*, iii) *elliptical top dome* and iv) *annular shells*; and that
  - the ingot casting was either i) conventional top cast or ii) bottom cast such as *Lingot a Solidification Dirigée* (LSD).

- ○ *All acceptance testing and analysis at that time had been supervised and checked by the Swiss regulator*

  The quality assurance and QT processes would normally involve a representative of the regulator, then HSK, visiting the place(s) of manufacture to check the procedures involved in both manufacture of the components – this might also have involved a visit(s) to the approved and certified test house or laboratory that undertook the physical testing and chemical analysis of the component parts. Technical aspects of these inspections would have been undertaken by the *Swiss Association for Technical Inspection* (SVTI – formerly SVDB).

  Even so, because the manufacturing, physical testing and analysis procedures are long drawn out, it is very unlikely that ENSI was actually present first-hand for *'all'* such testing and analysis and, almost certainly, for reasons of liability ENSI, in its role as nuclear safety regulator, would not have directly *'supervised'* any testing and/or analysis. Moreover, the usual arrangement in the application of the regulatory framework is with the 'contractual' ties limited to that between the regulator, here ENSI, and the NPP licensee or operator, here Axpo Holdings.

- Please confirm, or otherwise, that a representative(s) of ENSI (HSK) *'supervised'* and *'checked'* the tests and analyses; and that
- *'all'* tests and analyses were undertaken in the presence of ENSI.

o *The manufacturing specifications ("chemical analyses, material properties and tests") were met for all parameters*

For large steel forgings, it is simply not practicable to test all locations throughout the component because certain tests and analyses involve destructive routines that would render the component unusable.

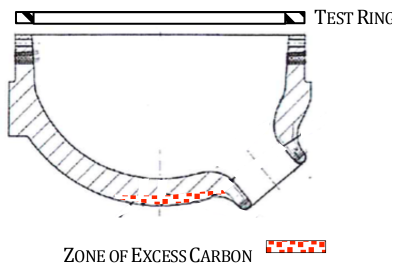
Instead, two safeguards are implemented:

The first is to manufacture each component in the same uniform and consistent manner – this is referred to as the conformity of the manufacturing route – on the basis that once the manufacturing route is proven and established then each successive component will be a true replicate, possessing the same physical and chemical properties and characteristics. If so, only the first, prototype component needs to be destructively tested and chemically analysed.

The second safeguard is to sacrifice a piece of the forging not required in the final component for testing and analysis. For domed components like the SG bottom channel head and elliptical dome this is referred to as the *'test ring'* which is trepanned from the component once that it has passed through all of the forging and annealing processes and successive. The test ring is sliced into a series of coupons, representing the major axes of the parent component with these then being subject to destructive physical tests and chemical analysis.

Physical testing includes the Charpy impact for toughness and vulnerability to crack propagation; Pellini for determining the material crack arrest property; and elongation to determine the ductility or elasticity of the material. Chemical analysis examines the material at a micro-level, for example by comparing the alloying elements locally with the original ladle analysis taken at the time of casting the ingot.

However, retesting of scrapped components has shown that the test ring may not be representative of the remainder of the component – for example, EdF Energy (UK) abandoned its reliance upon the Creusot test ring results in its re-assessment of the Sizewell B RPV compoments. In the bottom channel head example (right), the test ring (shown slightly detached for clarity) is remote from the site of the undesirable positive macrosegregation and excess carbon located in the bottom central section of the dome.



- For each of the SG components previously identified and for the Beznau Unit 1 and 2 RSGs, please provide copies of
  - i) the ladle analysis taken at the time of the ingot casting compared to the design specification of the alloying content;

ii) the Charpy (0°C), Pellini and Elongation test results in single and average test results (as specified) compared to the specified minimal requirements;

iii) a description of any non-destructive examination (NDE) undertaken on the RSG components since ENSI learning of the Creusot Forge carbon anomaly; and

iv) the most recent assessment of ductility transition temperature RT_{ndt} and the K_{Ic} *Master Curve* as defined by ASME NB2331.

o *The manufacturing documentation is complete and there is no indication of flaws in the quality of the material*

As previously noted, so far as the components destined for operational French NPPs is concerned, the situation with regard to the manufacturing QT documentation and records is presently in a state of flux, particularly with AREVA now returning to further scrutinize 9,000 files at Creusot. Also, the reliability of the information and data contained within the QT documentation has to be doubted with *Le Haut Comité pour la transparence et l'information sur la sécurité 6iles6ire* (HCTISN) reporting the actual forging parameters applied during the manufacture are now untraceable since (on an unspecified number of instances) the '*target* values had been recorded instead of the *actual* values presiding during the manufacturing of the component'.

Other doubts about the recording and reporting of manufacturing data at Creusot Forge have also raised concern with the US Nuclear Regulatory Commission in that it was not being informed about deviations from the specification; with ASN that manufacturing issues were not relayed to the customer (EdF); and that ASN has now acknowledged that a series of *Counterfeit, Fraudulent and Substandard items* (CFSIs) have occurred in the French nuclear supply chain.

The point here is that it is difficult to establish the integrity of the records that ENSI relies upon. The *'irregularities'* discovered to date by the French investigations, even though confined to components in the French NPPs, do not bode well for the reliability of any component manufactured at Creusot.

- Relating to the manufacturing records and the conformity of the processes undertaken by Creusot Forge, please provide

  i) the standard or code (eg M140 under RCC-M) required by ENSI to maintain quality control and adequacy of the manufacturing , testing and analysis processes undertaken at Creusot;

  ii) the date(s) on which the manufacturing records were inspected by ENSI;

  iii) the assurances given that the records were reliable; and

  iv) if, following the recent announcement by AREVA-ASN that 9,000 Creusot QT records are to be re-examined, it is the intent of ENSI to scrutinize the Beznau Units 1 and 2 RSG 6files again.

o *The forged pieces of the Beznau SGs were manufactured out of relatively small ingots, which aren't that much affected by segregation like the heads of FL3 e.g.*

The formation of segregates is a function of the non-linear heat transfer rates assumed in the molten ingot during its cooling and uneven transmogrification to a mushy and final solid states – this process occurs irrespective of ingot size, so knowledge of where the formation of segregates is within the ingot is essential because segregate discard can only be dealt with in the early stages of working the ingot. The important manufacturing parameter is the *forging ratio* which is, essentially, the amount of surplus provided by the volume of the original ingot that allows it to be cropped to discard parts of the ingot containing macrosegregation zones.

It should be noted (and must now be known to ENSI) that the JCFC flawed *bottom channel head* component RSGs installed in a number of operational French NPPs were of the same order of size as the Beznau RSGs.

- Please provide further information and justification of the factors that exempt and exclude the *bottom channel head* components of the RSGs of Beznau Unit 1 and 2 from the formation and retention of positive macrosegregation zones as, for example, found in the JCFC and Creusot manufactured components presently under investigation by the French nuclear safety regulator ASN.

Finally, you ask the following: -

1) **Did Acceptance Testing take place in France:** Yes - in France the RCC-M M140 code requires the material strength and characteristics to be demonstrated by way of physical testing and analysis – in 2005 ASN introduced a further requirement (ESPN) that required demonstration that levels of heterogeneity within the forged steel alloy were within acceptable bands and prior to acceptance into the nuclear supply chain, the component and its specific manufacturing route must have a *Certificate of Conformity* issued by ASN – the so-called design-basis defines the structural performance of all safety related components (essentially class N1) in terms of material characteristics, such as toughness and elongation %.

2) **Types of Ingot:** Essentially, there are two types of ingot commonly used by forges: The first is referred to as a conventional, top-poured ingot formed by feeding the molten melt directly into the top of the open mould and, a second, where the melt is poured into a riser arranged to enter the mould from the bottom (ie LSD referred to earlier) – both result in differing locations and zones of positive macrosegregation in the billet or bloom that requires cropping and discarding. It is not established which or both of these preliminary forging stages were adopted in the manufacture of the Beznau RSG domes components (bottom channel heads and elliptical domes) although for the annular shells it is most likely that the top poured conventional ingot would have applied.

Also, not all large, steel components are manufactured by upset (high pressure) forging since it is also practicable to form shell or dome components by hot pressing a previously strand (continuously) cast steel slab over a former – such hot forming is also at risk of macrosegregation zones formed during the strand casting process.