PWR Airborne Tritium
&
Review of RG 1.21 data

S. Sandike

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EnvoNuTek, llc

PWR Tritium Production, Review

- Tritium is produced primarily from neutron capture by B-10 in a PWR.
- Boric acid is added to PWR reactor coolant system (RCS) as a soluble reactivity shim.
- Boron (enriched in B-10) is used in PWR fuel assemblies as a burnable poison.

PWR Tritium Production

Neutron capture by B-10 has several results:

- $_{5}B^{10} + _{0}n^{1} \rightarrow [_{5}B^{11}]^{*} \longrightarrow _{3}Li^{7} + _{2}He^{4}$

$_{5}B^{10} + _{0}n^{1} \rightarrow [_{5}B^{11}]^{*} \longrightarrow _{1}H^{3} + 2(_{2}He^{4})$

Lithium is used in PWR Reactor Coolant pH control, to balance the effect of the chemical shim.

Tritium production is primarily from B-10 in the spent fuel pools, ventilated out through monitoring equipment, to the main plant vent.

PWR Tritium Production

- Approx 90% of the total tritium in PWR reactor coolant is produced in the coolant by the soluble boric acid reactivity shim.
- The remaining 10% is produced by ternary fission, B-10 burnable poisons, Li-6 neutron capture, and deuterium activation.
- BWR tritium production is significantly lower than PWR due to absence of boric acid in the coolant.

Industry Trend – Increased Airborne H-3

- PWR Tritium Production has increased over the last decade due to 24 month cycles and power uprates.

- Increased boron causes an increase in tritium and ternary fission

Converting Liquid H-3 to Airborne

- A few sites still use boric acid evaporators or otherwise attempt to eliminate liquid waste, and convert liquid H-3 to airborne effluent.

- These plants are outliers in comparison to other PWRs, where the airborne H-3 curies are defined primarily by the size and uCi/ml of H-3 in the Spent Fuel Pools.

Spent Fuel Pool H-3

- Increases with plant age (mixing during RFO)
- Can sharply increase during re-rack or ISFSI operation.
- Careless addition of RCS to the pool can have a very significant and long lasting effect on total pool H-3 inventory.
- Ventilation systems are designed to sweep the pool and remove H-3 as water evaporates.

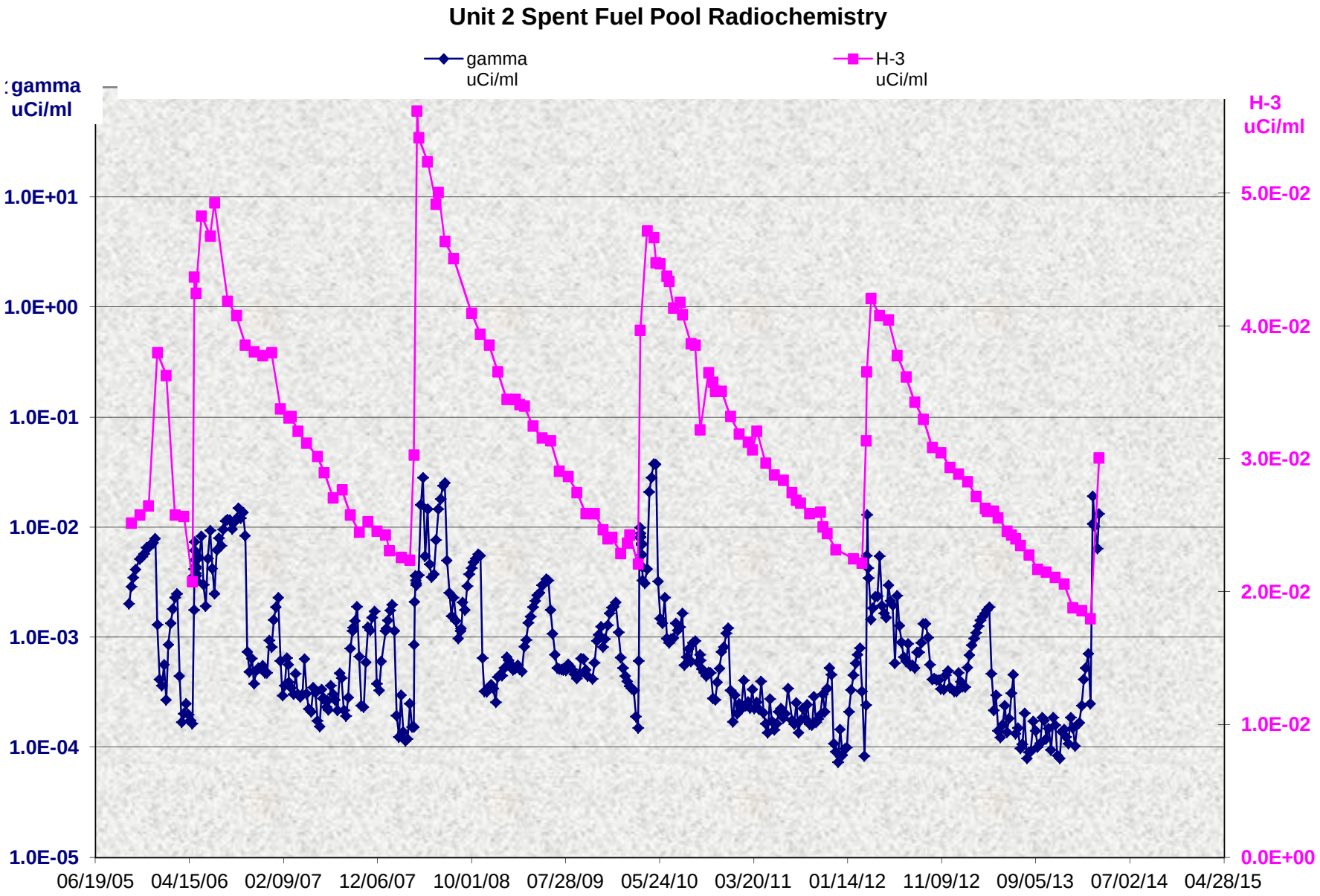
Factors effecting quantification of Airborne Tritium in PWRs

- NUREG 1301 allows batch sampling, once per month, and has a questionable LLD of 1E-6 uCi/cc.
- There is an assumption that ventilation is in fact, continuously in place.
- Any method of Airborne H-3 monitoring includes numerous opportunities for very real (perhaps likely) error traps.
- Sample collection methods differ between batch (cold trap or bubbler) and continuous (silica gel).

What can be done to improve airborne H-3 quantification?

- Unlike most other processes, airborne H-3 effluent can be assessed with relatively easy mass balances of the pool inventory.
- Most plants have pool level instrumentation, or at least logs that identify when water is added to the pool.
- Because ~90% of PWR airborne H-3 is from the pool, careful collection of this data can provide a way to verify integrated releases of H-3 determined from sampling.
- Comparison of these two processes can confirm your sampling technique, or tell you there is work to be done.

Typical SPF activity over a few cycles



Simple Method

- During a period of relative inactivity in the pool, simply multiply liquid concentration at start and end, by the relatively constant volume of the pool.
- The difference in curies should make up about 90% (or more) of the quantified airborne H-3 determined from plant vent sampling, unless there are numerous RCS leaks in containment or the aux building.
- Simply choose a long enough period, without RFO, re-racking, or ISFSI operation, to give you good statistics, and determine, for example, a monthly average value.
- Compare mass balance curies to the value obtained from your chosen sampling technique.

More Detailed Method

- Obtain detailed information regarding precise volumes of water added to the pool (from Ops or Eng).
  - This may involve SOP changes for Ops Watch-Standers, so they know to forward this info immediately to Chemistry, and/or to log the information so as not to miss any addition.
- Again, over a period of no disruption in the pool, the total volume of water added should approximate the mass that has been evaporated over the period.
- Obtain an average concentration of the pool activity over this period (or integrate this effort with pool activity as it decreases) to determine the total curies released.
- Compare results with quantification from sampling.

What if results are not pretty?

- A significant and repeated disparity in the quantified H-3 released from sampling and from pool mass balances should initiate an investigation.

- First, be sure there wasn’t a valid reason for the disparity (SFP operation, changing source term, re-racking, etc).

Some causes for a disparity

- Quantification with Silica Gel, although continuous, is cumbersome, time-consuming, expensive, and can be just as inaccurate as batch sampling due to handling, weighing, distilling, etc.
- While batch sampling once/month is allowed, this clearly assumes a relatively constant release rate up the vent.
  - Is that the case? How do you know?
- Non-continuous (intermittent) use of the Fuel Storage Building ventilation system can significantly skew this balance!

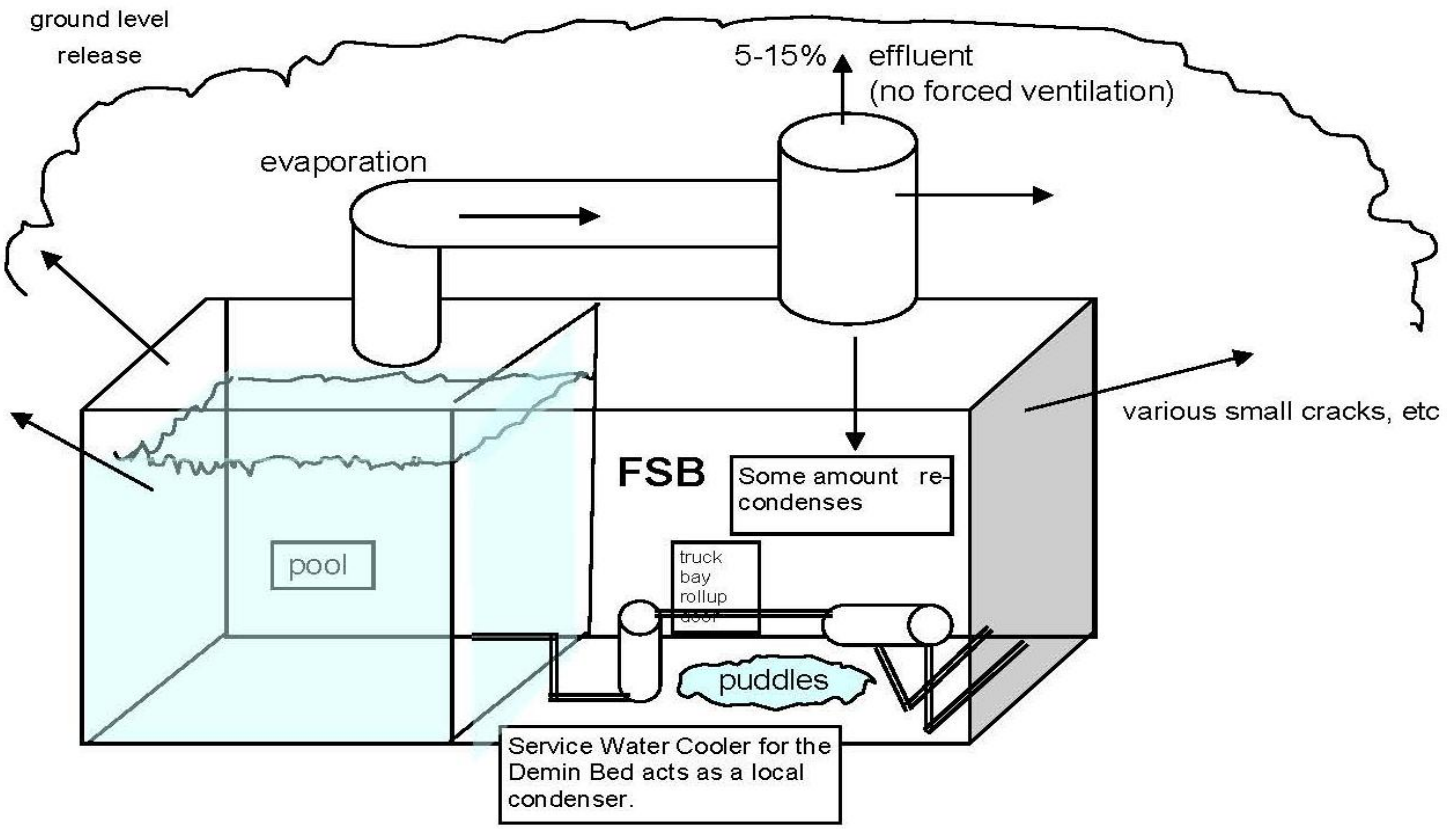
Intermittent FSB ventilation

- GDC states that the ventilation system is always running during normal plant ops.
- Are replacement fans available?
- What happens when the fan is “run to failure”?
- Does station management imagine that running the exhaust fan is “optional”?

An attempt to quantify H-3 releases from a FSB without ventilation

Add Date	inches added	Delta Days	gallons PW added	SFP H-3 uCi/cc	Non Re-condensed fraction	Ci H-3 lost
07-01-11	1	0	610	7.76E-02	1.50E-01	2.69E-02
07-13-11	4	12	2440	7.76E-02	1.50E-01	1.08E-01
08-01-11	1	19	610	7.76E-02	1.50E-01	2.69E-02
		31				**1.61E-01** curies

Ground level releases of H-3, determined from water added to pool, during the entire month.

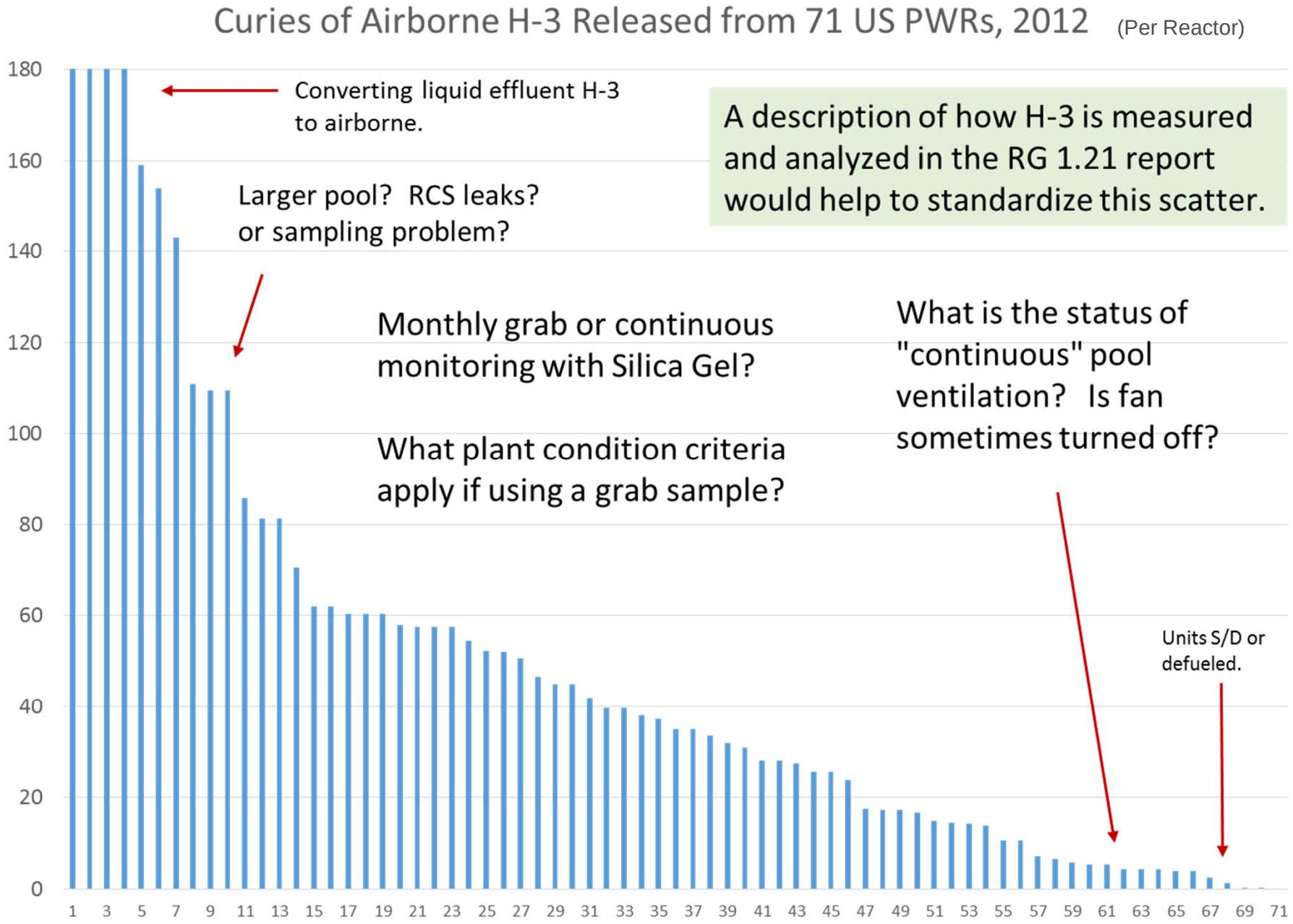


“It’s too cold in here”

- A possible scenario in the north: a less-than-carefully evaluated decision by a watch-stander results in turning off the exhaust fan when it’s cold outside.
- It is common to use plant steam in coils at the supply fan plenum to heat the Fuel Storage Building during winter. These coils often lack PMs and eventually leak due to the pH control in plant steam, or just due to neglect.
- To avoid water pouring over the floor, these broken coils are then sometimes isolated, leaving no means of temperature control in the building.
- An enterprising young NPO then mistakes the exhaust fan ON/OFF switch for a thermostat, and secures the exhaust fan to keep the building more “comfortable”.

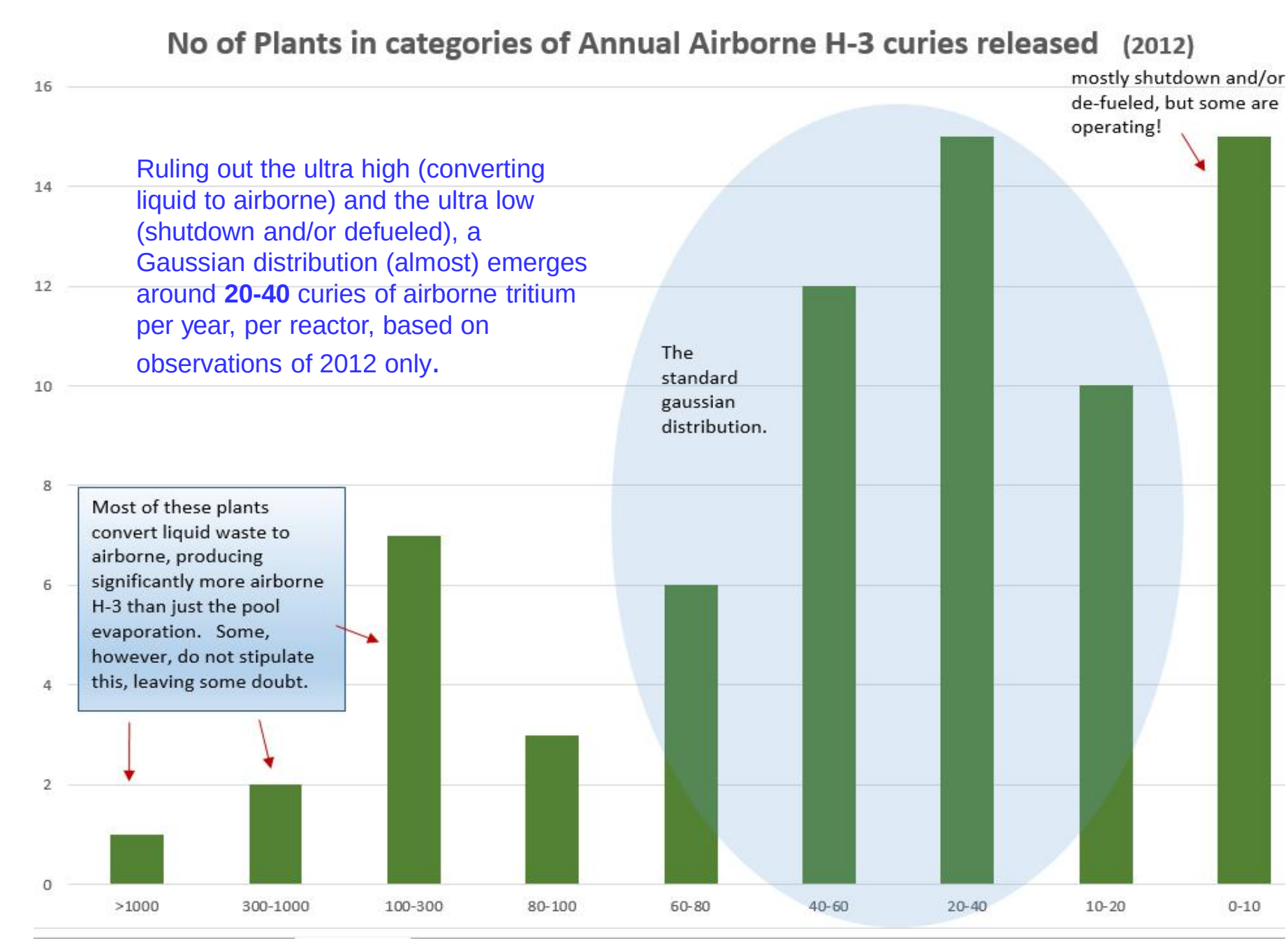
100% Humidity is rarely comfortable

- It’s also not entirely per design specification.
- “Storing” airborne H-3 in this water vapor over the pool results in loss of control of effluents, and possible issues with “failure to survey”.
- Typically, this kind of operation can also lead to enhanced local re-condensation as H-3 escapes out the supply or exhaust plenum (or any other holes) at ground level. It then re-appears in local storm drains. A real pain to monitor.


Curies of Airborne H-3 Released from 71 US PWRs, 2012
(Per Reactor)
180
160
140
120
100
80
60
40
20
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71
Converting liquid effluent H-3 to airborne.
Larger pool? RCS leaks? or sampling problem?
Monthly grab or continuous monitoring with Silica Gel?
What plant condition criteria apply if using a grab sample?
A description of how H-3 is measured and analyzed in the RG 1.21 report would help to standardize this scatter.
What is the status of "continuous" pool ventilation? Is fan sometimes turned off?
Units S/D or defueled.

Comparison of RG 1.21 H-3

- Can’t really make any conclusions without knowing operational objectives, pool size, status of fuel, concentration in the pool, many other parameters.
- But we CAN recognize that this data is very widely scattered and deserves some verification.
- It can and should be verified independently at each facility with your own specifics, using spent fuel pool mass balance testing.


No of Plants in categories of Annual Airborne H-3 curies released (2012)
mostly shutdown and/or de-fueled, but some are operating!
Ruling out the ultra high (converting liquid to airborne) and the ultra low (shutdown and/or defueled), a Gaussian distribution (almost) emerges around 20-40 curies of airborne tritium per year, per reactor, based on observations of 2012 only.
The standard gaussian distribution.
Most of these plants convert liquid waste to airborne, producing significantly more airborne H-3 than just the pool evaporation. Some, however, do not stipulate this, leaving some doubt.
16
14
12
10
8
6
4
2
0
>1000
300-1000
100-300
80-100
60-80
40-60
20-40
10-20
0-10
Curies of Airborne H-3 released

Your reported airborne curies

- The previous slides of industry comparison do not suggest your numbers are wrong or right.

- However, given the spread of this data and the likelihood of error and variability in sampling, it may be more than just beneficial to verify your H-3 determination with a spent fuel pool mass balance, at least periodically.

- Especially true if you
  - 1) are an outlier with curies,
  - 2) suspect trouble with FSB ventilation, or
  - 3) suspect batch sampling to be less than totally representative.

Example of simple balance

	H-3 Loss to Evaporation Calculation			
	Voume of pool:		280,000	gallons
	Activity start:	Activity end	Activity lost	
	uCi/ml	uCi/ml	Curies	
Cycle 21	4.20E-02	1.80E-02	25.4	
Cycle 20	4.72E-02	2.22E-02	26.5	
Cycle 19	5.26E-02	2.29E-02	31.5	
Cycle 18	4.93E-02	2.24E-02	28.5	

Additional rigor can be added as necessary for half life correction, etc.

Addition rate to pool method

Add Date	inches added	Delta Days	gallons PW added	SFP H-3 uCi/cc	Ci H-3 lost
01-03-07	6	16	3659	3.80E-02	0.526
01-15-07	5	12	3049	3.80E-02	0.439
01-29-07	6	14	3659	3.38E-02	0.468
02-05-07	6	7	3659	3.38E-02	0.468
02-12-07	5	7	3049	3.31E-02	0.382
02-26-07	5	14	3049	3.32E-02	0.383
03-03-07	6	5	3659	3.32E-02	0.460
03-13-07	4	10	2439	3.21E-02	0.296
03-20-07	6	7	3659	3.21E-02	0.445
03-27-07	5	7	3049	3.21E-02	0.370
04-04-07	6	8	3659	3.12E-02	0.432
04-15-07	5	11	3049	3.12E-02	0.360
04-22-07	6	7	3659	3.12E-02	0.432
05-04-07	4	12	2439	3.02E-02	0.279
05-14-07	6	10	3659	3.02E-02	0.418

This method involves knowing a conversion from inches to gallons with regard to pool level. Some facilities have pool level in the plant computer.

Benefits

- This kind of self assessment is beneficial for understanding your processes, as well as with regard to regulatory compliance and inspections.
- You may discover that your chosen sampling regime is flawed, and are under or over reporting tritium effluent.
- You may also determine that you may have a larger issue with escaping H-3 or leaks, heretofore, unknown.