I have read the email copies that you mailed regarding "Hydrogen Embrittlement" (HE). I have subsequently screened the most of available current literature for applicable information on the subject.

Thus far, I have not been able to find any studies regarding the possible progression of hydrogen absorption by high-strength and allow steels in atmospheric conditions over very long periods of time (decades). Most current literature deals with hydrogen embrittlement that occurs in parts during 'finishing' (i.e.: cleaning, plating, polishing, etc.). This type of HE occurs very quickly (in a matter of a very few minutes), and the current wisdom is that post-finishing treatments to drive out the hydrogen must occur within one to four hours after the processing that introduced the hydrogen. This is not the mechanism of HE that we are potentially encountering in old mainsprings. And, not surprisingly, I could not find any studies specifically on HE in 50-100 year old PW mainsprings.

Boeing has published a plan for testing for what they call "Hydrogen Re-embrittlement" of aircraft components. This study plans to investigate HE of high-strength aircraft components while in actual service in atmospheric conditions over the life of the aircraft. This study will be of interest to us, but is not complete (if fully underway at this time).

It is clear, however, that there is still a great deal that is not known or understood about HE. It is also clear that determining if the failure of a part (say a mainspring) was actually caused directly by HE, or by some other failure mechanism, requires very sophisticated testing that we do not have available. The best we are going to be able to do is process the mainsprings in such a way that would drive out (or "redistribute") the hydrogen (if it is actually there) so that it cannot 'directly' cause a failure in future use of the mainspring.

The following are specific points of information obtained from the literature I have been able to find as it seems to relate to our situation.

1. The "harder" the material is in the finished mainspring, the more subject it is to HE. Low carbon, soft steels are not subject to HE. The steel must have been hardened, or hardened and tempered, to be subject to HE. Since 'blue' steel mainsprings are hardened and tempered, they are certainly subject to HE. The higher the final temper (the harder), the more subject they are to HE.

2. HE occurs when active, "nascent" hydrogen (H1) is absorbed into the boundaries between the grains (Martensite) of hardened steel. This hydrogen restricts movement between the grains and makes the steel more brittle (less ductile). In this condition the material cannot deflect (flex) as it normally would without cracking.

3. Absorbed hydrogen can be driven out of the steel (or redistributed) by a "baking" process. If the steel is not otherwise damaged (corroded or cracked), the ductility of the steel will be restored to its original condition after proper baking. Note here that the key here is "if the steel is not otherwise damaged".

3. Steel that has absorbed hydrogen (that is hydrogen embrittled) should not be flexed before it is baked to drive out the hydrogen. Flexing the hydrogen embrittled steel can cause cracks to form wherever tensile (stretching) stresses occur due to flexing. Thus, baking should be performed on the mainspring before it is removed from storage coil ring.

5. HE can cause or promote other failure mechanisms such as "Stress-Corrosion Cracking". Stress Corrosion Cracking (SCC) results from two conjunct conditions. First, a surface of the steel must be subject to "tensile" (stretching) stress. Second, corrosion occurs in the grain boundaries in the surface 'opened' by the stress. This microscopic corrosion continues down the grain boundaries, separating the grains, and causing cracks. The tensile stress can be 'residual' stress from the initial manufacturing process (rolling, drawing, grinding, welding, etc.), or it can be 'applied' stress that results from coiling the spring into its storage coil ring. SCC can be present even when surface corrosion is not visible under optical magnification. As hydrogen embrittlement proceeds over time, it increases the risk that CSS will occur. However, it must be noted that SCC does occur in the presence of tensile stress and normal atmospheric conditions; without the occurrence of HE. Thus, springs may form cracks through SCC or other mechanisms even if hydrogen embrittlement does not occur.

6. 'Baking' the steel to drive out absorbed hydrogen will not "heal" cracks that have formed due to Stress Corrosion Cracking (or cracks formed by other mechanisms) over time. Even if hydrogen is driven out of the steel by proper baking, the spring may still fail due to cracks formed during years of storage. Thus, baking the springs may "rejuvenate" the original ductility of undamaged steel. But, baking will not "rejuvenate" (as in "heal") cracks that have already formed. And, such cracks (particularly SCC cracks) are not likely to be detectable under optical magnification.

7. There are several specifications for "baking" to relieve hydrogen embrittlement. Apparently the specification in most common use in the US today is ASTM B 850-98(2004). This standard requires baking the steel at 374-428 degrees F. The minimum bake time for the softest steel requiring this treatment is eight (8) hours, minimum. The hardest steels require baking for 22 hours, minimum.

I am unable to find any published information of the typical hardness of steel mainsprings. If you can determine from any source the typical hardness of mainspring steel, I will be better able to suggest a more appropriate bake time.

One of the emails you sent me states that Mainsprings were tempered at around 700 degrees F. I cannot find any mainspring processing information to confirm or refute this statement. However, if this temperature is assumed from the blue color of steel mainsprings, it must be noted that the blue color could have been obtained at temperatures ranging from 490 F to 710 F depending on the length of time the springs were held in the tempering oven. In any event, baking the springs at 374-428 F should not soften the springs.

I note also that one of your colleagues cites "recent reports of the discontinuance of the manufacture of many alloy replacement springs may leave us with no alternative...." It would appear that there are others who are not worth listening to other than my colleagues and me.

My suggestions for treating old, steel mainsprings.

1. Without removing the mainspring from its storage coil ring, ultrasonically clean the mainspring in an aggressive, non-oily hydrocarbon solvent. White gas, lacquer thinner, or even acetone should be acceptable. This is to remove as much residual oil as possible WITHOUT flexing the spring. Any residual oils may be hardened onto the spring during the subsequent baking.
2. Without removing the mainspring from its storage coil ring, bake the mainspring at 374-428 F (400 F nominal oven setting) for 8-12 hours; longer will not hurt.
3. Only after baking, remove the spring from its storage coil ring. For those mainsprings that were placed in paper envelopes without a storage coil ring, I suggest cutting the envelope away from the spring and avoid flexing as much as possible prior to solvent cleaning and baking.
4. Coat the spring with oil or grease as soon as possible after baking. If the spring must be re-cleaned after baking, I suggest that it be cleaned with solvent as before. We are uncertain of the constituents of watch cleaning fluids. Any low pH (and some high pH) solutions may cause hydrogen to again embrittle the old steel springs.

Do not be surprised if the mainspring still breaks after baking. If it does, we can only conclude that the spring was damaged by Stress Corrosion Cracking (SCC), residual stress cracking (Creep), surface corrosion, or an original flaw; none of which baking will correct.

Please call me if you have any questions, and if you are able to find any published information on steel mainspring hardness or tempering temperature.