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# FAQ on Some Fire Science Issues

### by Dr. Vyto Babrauskas

**Q:** What is the difference between watts (or kilowatts) and $kW/m^2$?

**A:** They are entirely different quantities. Watts measures the total power output of a fire. Power is defined as energy, divided by time. Thus, 1 W = 1 J/s, where J = joules is the measure of energy. The quantity $kW/m^2$, meanwhile may be describing a 'heat flux,' or a 'heat release rate.' Here, let's focus on heat flux, and we will talk about heat release rate below. Heat flux is the power that flows through an area equal to 1 $m^2$. The best way to visualize this is by a very simplified example. Suppose we have a 50 W incandescent light bulb. Thus, this device outputs power at a rate of 50 W. Let us assume that the power is radiated equally in all directions. (This will not be true, but we can visualize more easily such a simple example. Let make an imaginary sphere around the center of the light bulb with a radius of 1 m (39.36 inches). Physically, we can measure heat flux with an engineering device called a 'heat flux meter.' Let us place this device exactly 1 m away from the center of the light bulb, and point it directly at the center of the light bulb. What will this measuring device register? This problem actually has a simple mathematical solution. The surface area of a sphere = $4\pi r^2$, where r = radius. Since this light bulb radiates uniformly, any small chunk of area on the sphere will experience the same heat flux. So what is it? The arithmetic is simple: We have 50 W of power being emitted. This power is equally distributed over the area of the sphere. Remember that heat flux = power/area, where the area is the area of the receiving surface. In this case the area = $4\pi r^2 = 4\times 3.1416\times 1^2 = 12.57$ $m^2$. Then the heat flux our instrument will measure at the 1 m distance = 50/12.57 = 3.98 $W/m^2$. In fire science, we typically measure heat flux in units of $kW/m^2$, thus we get $0.001\times 3.98 = 0.00398$ $kW/m^2$. This of course is a very small number. Our intuition supports this, since clearly a 50 W light bulb will not be doing much heating at a distance of 39.36 inches. The example we gave here is very simplified and you can only make a relationship between power and heat flux to a very rough degree, in most practical cases. Note also that, in modern practice, we often write $kW\ m^{-2}$, instead of $kW/m^2$; both notations mean the same thing.

**Q:** "Heat flux" and "Heat Release Rate" are both heat per unit area quantities. So they are synonyms?

**A:** No! First of all, let me explain that I am describing terms in the context of what we in fire science use as our definitions. Other professions have different views. For example, in physics, the quantity we refer to as "heat flux" is called "heat flux density." Here we shall stick to fire science. First of all, HRR can be given either in units of kW, or in units of $kW/m^2$. When dealing with the burning of real objects (for instance, an upholstered chair), we report heat release rate (HRR) results in kW. This is because the area from which the heat is evolved is not fixed, but changes over the duration of the burn. Normally, we start with a small ignited area, then fire spreads to cover a larger surface area, then eventually the fire burns out and the burning area shrinks. But the hazard to people or external objects scales as the kW of the fire. In a bench-scale test, such as in the Cone Calorimeter, we measure a small sample. In the Cone, it is 100 x 100 mm, about 4 x 4 inches. This small fire would not be of danger to anyone, unless it is your clothing that is burning. To characterize the actual hazard, we will use some form of model to extrapolate from bench-scale to the real-life environment. The model can be as simple as an arithmetic formula, or as sophisticated as the FDS model. In FDS, the quantity is referred to as HRRPUA, heat-release-rate-per-unit-area. Now, with these preliminaries in hand, let us answer the question. In fire science, HRR is the **output** of a fire. Heat flux is variable used to describe the thermal attack, from a heater or from a flame. For instance, in the Cone Calorimeter, we apply a controlled heat flux from the heater onto the face of the specimen; this can be viewed as the **input** variable. There is no fixed relationship between this heat flux and the HRR of the specimen, it all depends on the nature of the specimen that is burning. Heat flux is also used to quantify the fire attack on objects in real fires. For example, we can measure the heat flux coming from the fire to the ceiling in a room fire experiment. We commonly measure HRR with an instrument based on the 'oxygen consumption' principle, which is a long story in itself. Conversely, we measure heat flux with a 'heat flux meter,' which is typically a small, water-cooled device which gives an electrical output proportional to the heat flux that is seen at its face. To put some dollar signs onto these things, an apparatus for measuring the HRR may cost you $100,000, while a heat flux meter may be around $1000. Neither one is likely to be acquired by other than laboratories engaged in fire research or fire testing.

**Q:** Is there some simple way to characterize the hazard, especially to humans, of a fire?

**A:** Yes! This was very hard to do until the 1980s. But in that decade, instruments became available to measure heat release rate, HRR. This turns out to be the key. In general, this has to be measured in full-scale, using something like the furniture calorimeter (an oxygen-consumption based, open HRR calorimeter). You may have heard that carbon monoxide (CO) poisoning is the most common cause of death from fire. That is true. But it turns out that the production of CO from a fire is correlated to its HRR. If you make a product have a low HRR, there is negligible likelihood that burning it will be the cause of someone dying from CO poisoning. Conversely, if some object has a high HRR, there generally is no practical way to lower its production of CO to make it safe.

**Q:** The **Smoldering Fires** book gives a lot of technical information on cigarettes. If I know some of the properties of a potentially ignitable material, how do I used this information to calculate if a cigarette can, or cannot, ignite it?

**A:** You cannot do this by calculation. The heat transfer situation at the interface between a burning cigarette and the substrate is very complex, and there is no practical way to compute the potential for ignition. Instead, what we do when we need this information is make actual measurements. And, of course, if a reliable source has made such measurements, we may be able to use this information. The **Smoldering Fires** book has some practical information on this issue, but the **Ignition Handbook** collects a great deal more of such information.

**Q:** What information do I need to obtain so that I would be able to calculate the ignition temperature of some combustible material that is of interest to me?

**A:** The basic information you need to know is the amount of funds you have in your bank account. You will need to fund a Ph.D. student for three years, so that they will be able to get the correct answer for you. This may cost more than you want to pay. The more practical way to find out the ignition temperature of some material where this information is not already available in the literature is to get an ASTM D1929 ignition test run on it. This will only cost you a couple of hundred dollars. The **Ignition Handbook** has published ignition temperatures for quite a few common materials. If you cannot find your material there, then you may want to search the internet for it, before paying to get the ASTM test run. But you will need to make some assessment on whether a value that you find is likely to be reliable. The simplest reality check for this is if you can find a chemically somewhat similar material where values have been published in the **Ignition Handbook**. In such a case, you expect that if the materials are chemically similar, their ignition temperatures should not be too different. The ASTM test is the only standard test for ignition temperatures. But it is also possible to get the needed information from non-standard testing. For example, Cone Calorimeter samples are sometimes fitted with thermocouples to obtain ignition temperatures. This had been done at a lot of labs, even though no standard is published on how to do it. Either way is perfectly good for getting this information.

**Q:** In the **Ignition Handbook**, for some plastics, there is quite a broad range of ignition temperatures given. Why is that so?

**A:** A concerted effort was made in providing this compilation to exclude any sources of data which were suspected of being of poor quality. But experimental data scatter can never be eliminated. More of an issue with regards to plastics, however, is the composition of the tested material. In many cases, additives used in the particular formulation may make a difference. But it must also be remembered that the polymers themselves are not simple molecules. Thus, even ‘pure’ polymers can be chemically different due to factors such as degree of polymerization. Thus, data scatter for plastics will always be greater than for pure liquid or gas samples.

**Q:** What are “confined” fires?

**A:** Thus is a terminology which NFPA often uses in its reports. What they mean by this term is that the fire was confined to the object of origin. This is a tricky situation, because the Consumer Product Safety Commission, CPSC, sponsored two studies to find out the frequency of unreported fires. The national fire statistics database, NFIRS, only collects statistics from fire departments. These, in turn, only find out about fires where somebody calls them about the fire. But it turns out that way more fires are unreported, than reported. The CPSC surveys indicated that these are most often stovetop fires, where the householder successfully coped with the incident and had no need to call for fire department intervention. Another common type is dumpster fires. But for those types of incidents, nonetheless, in some cases, the fire department does get called. This is especially true of dumpster fires, since people may call such fires in to make sure it does not spread. Thus, there are more than zero of such incidents in the NFIRS database. With confined fires, there will generally be no deaths, no ambulance calls, and typically no insurance claims. They are fires with negligible destruction. Note that “confined” fires does not include incidents where somebody ignited their clothing and sustained burn injuries, even if the fire does not spread beyond the person’s clothing. This of course is due to the injury aspect.