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BREMSSTRAHLUNG - RELATIVE ROLE IN HOT AND COLD FUSION AND IMPACT UPON POTENTIAL ISOTOPIC FUELS

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ABSTRACT

Unlike hot fusion or plasma systems, bremsstrahlung radiation in cold fusion systems cannot dissipate fusion power through production of penetrating radiation. The bremsstrahlung radiant power from cold fusion differs from hot fusion in being markedly lower in intensity, with an output spectrum in the near infra-red. The cold fusion bremsstrahlung power density, relative to input power, falls from 0.05 - 0.28 (hot fusion) to only 1.4 - 8.1 x 10^{-10} for cold fusion. The delivered x-ray radiation dose (at 1 meter) decreases from 3.1 x 10^{19} Grays (hot fusion) to 1.4-3.3 x 10^{-4} Grays for cold fusion. These calculations are consistent with the relative absence of apparent ionizing emissions from cold fusion systems for both nickel-light water and palladium-heavy water systems.

The energy transfer in cold fusion systems via bremsstrahlung radiation is limited by the skin depth which for palladium (9.25 x 10^6 mhos/meter, 10^{13}-6 x10^{14} Hz) is 2.7-20.9 nanometers. One implication of the effective containment of the radiant bremstrahlung power, is its possible overlap with thermal and phonon processes. A corollary is that because of the much lower levels of bremsstrahlung power emitted, isotopic fuels of higher atomic number may be useful in cold fusion systems.

INTRODUCTION - Bremsstrahlung and Cold Fusion

There have been many suggested theories used to dismiss the extensive experimental observations of the cold fusion phenomena. Several of these purported reasons have been shown to be incorrect including the unusual and unexpected cold fusion branching ratio [1], recombination [2, 3, 4], special relativistic effects [1], and experimental issues involving sampling error, noise, and contamination [3, 4].

X-ray emissions, including bremsstrahlung [German for "braking (**brems**) radiation (**strahlung**)] emissions, have also been repeatedly cited as a theoretical reason to dismiss the extensive experimental observations of cold fusion. But this is incorrect on both logical, and quantitative, and spectral-emissive grounds. The issue is not that Bremsstrahlung emission rates from cold fusion cells are qualitatively lower than those emission rates from hot fusion plasmas, but that cold fusion reports have been dismissed by skeptics because of purported x-ray (and neutron) emissions which they claim must accompany cold fusion reactions at a level to create the purported "graduate student problem (read: survival after the experiment with negligible shielding)". This purported "miracle" of cold fusion concerning the relative absence of lethal ionizing radiation emission actually must pass a semiquantitative test. The other purported "miracle" was eliminated as a concern when the neutron emission channel was closer examined because it was shown to be ~1 MeV above the helium nucleus first excited state, and therefore unattainable at cold fusion temperatures [1] and hence, the channel is forbidden - consistent with observations. Therefore, x-ray bremsstrahlung emission – often invoked but rarely quantitatively considered – remains the only theoretical factor (other than coulomb barrier penetration and nuclear-coupling issues to the lattice) which skeptics can honestly use against cold fusion.

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Furthermore, accurate measurements of very low energy x-ray emissions from both nickel light water cells [5] and palladium heavy water cells [6] indicate levels on the order of background consistent with the actual calculation reported herein (Table 1). This paper, therefore, examines bremsstrahlung and its possible role in the cold fusion phenomena more closely considering the following questions: Is there bremsstrahlung in cold fusion? How would it differ from the extensively observed Bremsstrahlung in electron beam experiments, plasma systems, and hot fusion?

Electromagnetic Radiation Emitted has Many Components

Power loss from fusion systems (P_{LOSS}) has the usual components of radiation (P_{RAD}), conduction (P_{COND}) and convection (P_{CONV}). The power loss from radiation (P_{RAD}) as usually considered in hot fusion systems consists of radiation components secondary to bremsstrahlung (P_{BREM}), cyclotron radiation (P_{CYC}) , and optical emissions (P_{OP}) [7]. These are augmented here by three additional terms, which represent the effects of conduction and convection, that is, blackbody power emission (P_{BB}), heat (enthalpy) conduction (P_{ENTH}), and the power loss which may result through the exit gas stream (P_{GAS}). In cold fusion systems these must be included.

The heat conduction in hot fusion is usually handled through its implicit incorporation in the energy confinement time. Here, it is included explicitly in equation (1) because the excess enthalpy of cold fusion is the major signal of the desired reactions where optical phonons may play a significant role in hyrided lattices and their electronic behavior [8].

$$P_{LOSS} = P_{RAD} + P_{COND} + P_{CONVECT} = P_{BREM} + P_{CYC} + P_{OP} + P_{BB} + P_{ENTH} + P_{GAS} \quad (1)$$

Significant levels of bremsstrahlung occur at hot temperatures characteristic of plasmas. Because of the energies involved, the bremsstrahlung radiation is penetrating and cannot be contained. This is important because at relativistic energies, the energy loss by bremsstrahlung may exceed that secondary to all collision interactions with matter surrounding and within the reactor. Contrast this to hot fusion systems, where the energetic ions and electrons of the plasma radiate so much ionizing (x-ray) power by bremsstrahlung that this radiation leakage challenges reactor planning because it can effectively remove so much of the produced fusion power.

Bremsstrahlung [Breaking Radiation]

There are two well-known types of bremsstrahlung - outer and inner. Outer bremsstrahlung (output spectrum shown in Fig. 1) is the release of ionizing radiant energy from highly energetic moving charged particles upon their deceleration [9,10]. This form of bremsstrahlung was first observed when it produced secondary x-radiation from fast moving electrons hitting thick metallic targets. Inner bremsstrahlung occurs in β-decay and results in the emission of photons in energy between zero and the maximum energy available for that transition. Inner bremsstrahlung, double bremsstrahlung [11-13], polarization bremsstrahlung, solar bremsstrahlung [10] and the relativistic bremsstrahlung associated with hadronic showers including solutions by the Weizsacker-Williams method of virtual quanta will not be discussed in this paper.

This paper considers the energy range of the electromagnetic radiation emitted by Bremsstrahlung, the proportion of Bremsstrahlung to other energy losses including radiant and collisional, and in the case of fusion, the ratio of Bremsstrahlung power density to fusion power density.

Outer Bremsstrahlung Emission Spectrum

Bremsstrahlung, described by a theoretical energy spectrum and angular distribution [14, 15, 16], has an observed power output spectrum (confer fig. 1) as a function of the emitted photon energy. The output

spectral curves are continuous, but also contains characteristic material-specific photon peaks (lines) superimposed. The latter occurs from the displacement of lower-lying electrons in the target and the subsequent refilling of those orbitals. Fig. 1 was obtained by spectroscopy of bremsstrahlung emission from electrons of varying electrical accelerating potential which impinged upon a thick tungsten target. The peak emission outputs increase with applied electric potential. The 'white' light emission characteristics are shown which are very close to those of bremsstrahlung. The effect of filtration (discussed below) of 1 millimeter of aluminum is also shown in Fig. 1.

Bremsstrahlung Radiation Cross Section

The energy in the bremsstrahlung output spectrum (Fig. 1) is expressed for incident beam or gendanken experiments as a cross section of photon emission with dimensions of area/unit photon energy. This enables the determination of the beam energy loss as a function of distance ($\frac{dErad}{dx}$). The radiation cross section of bremsstrahlung has been considered several ways including classical, semiclassical quantum, and the Bethe-Heitler quantum mechanical Born approximation (done in 1934). Calculations usually begin with the kinetic energy of the moving particle considered, relativistically if necessary [17-19]. The radiation cross section is

$$X_q(\omega) \cong \frac{16}{3} \frac{Z_M^2 e^2}{c} \left(\frac{z^2 e^2}{Mc^2} \right)^2 (\frac{c}{v})^2 \ln \left(\frac{2\pi \lambda M v^2}{h\omega} \right) \qquad (2)$$

where the impact particle has charge ze, mass M, and velocity v, impinging upon a target material characterized by charge $Z_M e$. λ is a numerical factor, on the order of unity, used to correct for uncertainties regarding the impact parameters. It can be seen by inspection of Eq. (2) that emission of bremsstrahlung radiation is most important for low mass (m) particles impinging upon high atomic number materials (Z_M), and therefore for electrons impinging upon palladium (Z = 46) or nickel (Z = 28) would be well characterized by this equation.

For such beam experiments, the total energy loss over distance is therefore determined by the integration of the radiation cross section over all frequencies. If N is the number of fixed charges in a unit thickness, the energy loss per unit distance becomes

$$\frac{dErad}{dx} = N \int X_q(\omega)\, d\omega \qquad (3)$$

Eq. (3) is solved by use of conversion to a new variable of integration, $x = \geq \frac{h\omega}{2\pi E}$. The radiative loss per unit distance by bremstrahlung is thus

$$\frac{dErad}{dx} \cong \frac{16}{3} N * \left(\frac{2\pi Z_M^2 e^2}{hc} \right) * \left(\frac{z^4 e^4}{Mc^2} \right) \qquad (4)$$

Screening Effects for Sufficient Relativistic Energies

Screening effects due to the target atomic electrons have not been considered above, but are typically included through their relationship to the impact parameter. There is a critical energy (E_s) beyond which the impinging relativistic particles are said thereafter to have "complete" screening. The important result from screening considerations, discussed elsewhere, is that for all $E > E_s$, the bremsstrahlung radiation cross section changes and, thereafter for increasing frequencies, becomes constant. Where does this occur for the materials used in cold fusion? For beam systems where this has been experimentally confirmed, for electrons in aluminum (Z = 13) this critical energy, E_s, is about ~42 MeV, and for lead (Z =

82), the relevant relativistic energy E_s is ~23 MeV. This is characterized by

$$E_s = \left(\frac{192\,M}{Z_M^{1/3}\,m} \right) Mc^2 \tag{5}$$

Equation 5 was used to calculate the expected critical energy (E_s) for the hydrided materials associated with cold fusion. For electrons in palladium (Z = 46), this calculation is E_s = ~28 MeV. For nickel (Z = 28), it E_s ~33 MeV, and titanium (Z = 22), E_s ~35 MeV. The conclusion is that the bremsstrahlung screening effect is unimportant in this analysis of cold fusion systems.

Calculation of λ_{min}

By inspection, conservation of energy requires that the maximum wavelength of Bremsstrahlung emission be limited to, under non-relativistic conditions, the kinetic energy of the incident particle, and so $\frac{hc}{\lambda_{min}} \cong \frac{1}{2} Mv^2$. This has great impact upon radiation behavior. Therefore, the upper limit for photon energy emission occurs at the shortest wavelength (Angstroms) which is inversely dependent upon the voltage (V) used.

$$\lambda_{min} = \frac{hc}{eV} \cong \frac{12{,}396}{V} \tag{6}$$

The putative bremstrahlung of cold fusion differs from hot fusion due to the lower temperature. At cold fusion temperatures, circa 300 K implying equivalent energies of 1/40 electron volt, the maximum energy (minimum wavelength) output of Bremsstrahlung emission is in the near infra-red. Given this result, the most important implication is that cold fusion bremsstrahlung would have insignificant penetration of the electrode or even aqueous medium. The penetration depth, and its implications, will be calculated after first considering the relative role of bremsstrahlung radiation to all collision related energy losses.

Comparison to Collision Losses

It is important to compare the power loss by bremsstrahlung to power loss by collisions because these secondary collisions are quite numerous. This is important because each collision creates additional collision and radiation losses [16]. An impinging 1 MeV electron might undergo circa ~10,000 collision interactions before coming to "rest". The ratio of radiative energy loss to collisional loss can be written as

$$\frac{dErad}{dEcollision} = \frac{4}{3\pi} Z^2 \left(\frac{Z_M}{137} \right) \left(\frac{m}{M} \right) \left(\frac{v}{c} \right)^2 \frac{1}{\ln B_q} \tag{7}$$

B_q is impact parameter. There are several implications of this equation. The $(\frac{v}{c})^2$ term indicates that bremsstrahlung radiative loss is negligible for non-relativistic kinetic particles which are characterized by $v << c$. The $\left(\frac{m}{M} \right)$ term is consistent with the fact that the bremsstrahlung-related radiative loss results from deceleration of the incident particle (of mass m), whereas the remainder of the losses (collisional) involve the kinetic mass of the impacted material (mass M).

Bremsstrahlung Output Power Calculation

The standard calculation for plasma and hot fusion bremstrahlung requires determinations of both ion density and excitation energy. The bremsstrahlung power equation becomes

$$P_{BR} = 5.35 \times 10^{-31} f \sum_j k_j Z_j^2 * (n^2) * T_e^{1/2} \quad (8)$$

where $f = \sum_j k_j * Z$, the electron temperature is T_e (in keV), and there are n ions/cm^3, containing j nuclear species, of charge Z_j and of fraction density (sum =1) of $k_j * n$. Here Z is the nuclear charge, n_i and n_e are ion and electron densities (number of particles/cm^3) and T is the electron temperature [keV]. Table 1 compares the bremsstrahlung power density to estimated cold fusion power densities. The table shows the calculation for the applied voltage, the thermodynamic equivalent voltage for k_BT which is 1/40 eV. Also included is the maximum estimated voltage which might occur under some experimental setups under those conditions when electrical arcing is seen. This is limited by the expected dielectric breakdown of the materials.

Radiant X-ray Power

First, the **bremsstrahlung power volume** is much less at cold fusion (CF) temperatures (~300 K) than at thermonuclear temperatures. However, the determination as to whether bremsstrahlung is important for CF (as it is for thermonuclear fusion) also depends upon the ratio of bremstrahlung power to fusion power. In kinetic beam experiments as discussed above, it is also important to consider the radiant x-ray power in comparison to input electrical beam power. In the sense that cold fusion experiments also have central electrical input power distributions as the etiology of the fusion mechanism, this factor was also examined for the case of cold fusion although it may not be strictly applicable.

$$\eta = \frac{x\text{-}ray\ power}{beam\ power} = 0.0007 * Z * V \quad (9)$$

Table 1 list the results. The ratio of x-ray power to beam power falls from 0.05 - 0.28 (hot fusion, characterized by aluminum and lead targets, Table 1) to 1.4 - 8.1 x 10^{-10} for cold fusion (palladium Z = 42, and water (average Z = 8)).

Radiation Dose Delivered

This marked decrease in the exit of ionizing Bremsstrahlung radiation must be reflected in the radiation dose delivered. This can be calculated from the x-ray beam dose equation [20], here modified as the x-ray dose in Grays (at 1 meter) delivered per coulomb of electrical input.

$$D/Q = 1.50 * V_{max}^{2.8} * Z^{1/2} \quad \text{(Grays/Coulomb)} \quad (10)$$

V_{max} here is dominated by k_BT because the applied electrical field intensity, assuming homogeneous distribution over the system is insignificant by comparison. This most important result from equations 10 and 11 is the correct calculation of the derived value of the bremsstrahlung delivered dose at a distance of 1 meter for conventional fusion systems (Table 1). The radiation dose (Grays) per coulomb at 1 meter drops from ~3.1 x 10^{19} Grays (hot fusion) to 1.4-3.3 x 10^{-4} Grays for cold fusion.

Correlation with Experimental Results

This above result is consistent with experimental findings. Again there is no reason for the experimenters in cold fusion laboratories to have easily seen any ionizing radiation because, like neutrons, there are theoretical reasons for x-radiation to be absent. Some recent experiments are consistent with cold fusion (using the codepositional method) producing very low levels of ionizing energy release in the range of ~6

to 30 keV [6, 21] for Pd heavy-water systems, and on the order of background for the nickel light-water experiments [5]. The origin of these very low photoelectric ionizing emissions, if confirmed, is not clear but may be due to interactions involving the electrode material itself. Bremsstrahlung radiation (certainly in the ionizing radiation regime) has felt not to be characteristic of cold fusion experiments. We must now examine the impact of the fact that most of the Bremsstrahlung radiant power exists, in cold fusion systems, in the near-infrared.

Implications of Shift to Non-Ionizing IR Output

The shift of the cold fusion bremsstrahlung output power spectrum to non-penetrating radiant energies has great implications. The first implication of the maximum energy with cold fusion is the increase in the role of self-attenuation. As an example of how significant this effect might be, consider that small amount of even low-Z filtration produces the well-known effects of beam hardening widely used by radiologists for a century. This can be seen in Fig. 1 by comparing the filtered curves to those without that filtration. For example, when 65 keV electrons are bombarded into tungsten targets, the filtering of 1 mm aluminum alone cause all radiation below about 10 keV to drop to virtually zero.

The second implication is effective containment of the radiant bremsstrahlung power, and its overlap with thermal and phonon processes. With cold fusion, could the impact of this present serious and interesting physics because of the extremely limited skin depth? It must be true that the final boundary condition will be the Stefan-Boltzmann distribution of blackbody radiation characterizing the system. However, in this case, there is the additional, albeit small, localized input from the cold fusion bremsstrahlung radiation which may act to supplement the local phonon field.

Impact of Skin Depth

The loss of potential fusion energy through Bremsstrahlung radiation is very low for cold fusion systems because the radiation is in the near infrared and, therefore, is trapped by the skin depth effect to remain vicinal to the reactions. The infrared radiation is essentially locked into the materials, as opposed to the penetrating, uncontained, ionizing radiation of hot fusion (Table 1). The energy transfer in cold fusion through bremsstrahlung is limited by the skin depth which is relatively small. The skin depth is defined, in continuum terms, where σ is the conductivity, and μ the permeability, by

$$\delta_{skindepth} = \frac{2}{\sqrt{\omega * \mu * \sigma}} \tag{11}$$

For palladium (9.25×10^6 mhos/meter), at 1 Megahertz this is 0.066 mm, but in the infrared (10^{13} - 6×10^{14} Hz), the skin depth ranges from 2.7 to 20.9 nanometers (Table 1). This must be compared to the hot fusion bremsstrahlung which is very penetrating (Table 1) with tenth value thicknesses of lead ranging from 0.2 to 65 millimeters.

The result of equation 11, is that because of the skin depth, the energy of the bremsstrahlung radiation is trapped inside the metal, possibly in thermodynamic equilibrium, and can only exit by blackbody radiation, exit gas stream (or possibly monatomic gases, or ions, through catastrophic desorption) or further phonon conduction.

Relative Unimportance of $T^{1/2}$ Wall in Cold Fusion

The radiated power by bremsstrahlung is proportional to $T^{1/2}$ power, but for cold fusion the T is markedly lower. Fig. 2 considers equation 8 with ~5 MeV to represent the temperature of hot thermonuclear fusion. Cold fusion has an electron energy of k_B*T = ~1/40 eV at room temperature, although the plot permits

consideration of other voltages (Table 1). Equation 8 predicts, assuming it holds for such cases, results which are shown in Fig. 1, and which are presented as the relative radiated power by Bremsstrahlung for both hot and cold fusion. The relative radiated power is shown as a function of electron temperature for different atomic charge.

Fig. 2 shows the impact of the different operating temperatures in the two fusion systems. Once again, such assumptions about hot fusion do not necessarily have the same implications for cold fusion. In this case the expected bremsstrahlung power radiation factor -- even if applicable -- may be only <<1% of what is expected for hot fusion systems. Given the temperatures and the bremsstrahlung power radiation factor (eq. 8), there is a maximum ratio of ~0.002 as the temperature correction factor when the plasma bremsstrahlung power radiation equation for cold fusion systems.

Possible Secondary Effects

In summary, leakage of radiation energy within cold fusion systems by bremsstrahlung is found to be much less important by quantity than for conventional hot fusion systems. There are three things to consider. How will the energy be lost? Is there an impact of the retained energy upon the fusion reactor its component materials, or the desired reactions? Are any limitations changed in cold fusion as compared with hot fusion?

First, the bremsstrahlung power which radiates will remain trapped until either blackbody radiation or phonons carry off the energy. The Boltzmann constant 5.67×10^{-8} W/m^2 - K^4 indicates how fast (or slowly) further loss will occur by such radiative process (P_{BB}). Faster routes include, first, the phonon heat transfer routes because their rates exceed radiant heat transport rates by some six to eight orders of magnitude.

Second, some limitations do appear to be possibly changed in cold fusion as compared with hot fusion. Unlike the continuing of leakage of momentum and energy in hot fusion, in cold fusion the output spectrum of bremsstrahlung being in the near IR couples to the electrode, indicates that cold fusion Bremsstrahlung might not exactly follow the "$T^{1/2}$ power wall behavior" which limits hot fusion systems. Instead there may be further reaction with the very hydrided lattice that produced the desired fusion reactions. Other limitations involving possible changes in fuels will be discussed below.

Third, consideration of how bremsstrahlung power loss might influence cold fusion is very complicated. It is important to note that putative bremsstrahlung, produced by slowing of a putative energetic CF product particle, would only occur **after** the cold fusion reaction(s) have already occurred, and therefore removal of energy and momentum from the reactions is involved. The bremsstrahlung coupling to the local lattice may have several late effects. These might include either dampening (or accelerating) the effect and/or changing the lattice itself.

Could this infrared radiation, secondary to Bremsstrahlung, explain either the unusual cold fusion branching ratio, coupling to the lattice, or the increase in fusion rates over conventional calculations? The locked in radiant bremsstrahlung may be small in comparison to the optical phonons in the hydrided material, but it may produce further contributions that might enhance, or inhibit, the desired reactions. To the degree the cold fusion reactions, or the reactions that proceed or activate them, are extremely temperature sensitive, the spatial locking-in of the bremsstrahlung radiation might inhibit the cold fusion reactions by removing power from the local of the fusion reactions, thereby braking the desired reactions. Given the skin depth, such power loss is insignificant compared to hot fusion and does not seem likely to be sufficient to cause serious cooling in the solid.

However, more importantly, the lock-in effect means that there may be additional post-fusion contributions to the optical phonons. These lattice vibrations have coupling in the infrared, which itself is linked with molecular vibrations. Given the lattice, additional phonons would thereafter develop. To the degree that

these phonons are needed to continue further CF reactions, the cold fusion bremsstrahlung might accelerate the desired reactions. There may be theoretical reasons to believe that nuclear-to-lattice coupling of cold fusion might proceed through nonlinear phonon effects (Hag [8], Phonon). There is preliminary evidence in some of our experiments that sudden loss of heat from the cold fusion reactors might be markedly influencing the fusion reaction rate. Efforts are ongoing to determine why and to quantify the effect. Furthermore, it is known that there can be focusing of phonon, and diffusive hydride-flux energy toward those few select sites where the reaction can occur.[1,22] The contribution of cold fusion bremsstrahlung might enhance this focusing effect as well.

COULD MID-Z ELEMENTS BE FUELS?

There is a second important result and implication. For example, both the ratio of Bremsstrahlung to ionizing effects may be significant. Also, isotopic fuels of higher atomic number may be useful in cold fusion systems. As Fig. 2 shows, the Z dependence makes bremsstrahlung power loss greater than potential fusion power gain at hot fusion temperatures, except for the very few cases of low-Z elements.

However, at cold fusion temperatures, this atomic charge restriction regarding fusion may actually be less secure. Given the reported putative transmutations observed during some cold fusion experiments, this analysis also suggests that even when Bremsstrahlung power radiation might be limiting to the attainment of successful fusion systems, isotopic fuels of higher atomic number than normally considered for hot fusion may be useful in cold fusion systems. If the conditions are limiting, and the physics is the same as described by eq. (3), then the isotopic fuels could include at least second and third row elements, possibly even potassium.

SUMMARY

We have examined the role of bremsstrahlung in cold fusion systems. The critical bremsstrahlung screening frequency for electrons in palladium ~28 MeV (nickel Es ~33 MeV). Unlike hot fusion or plasma systems, by magnitude bremsstrahlung radiation in cold fusion systems does not play a dominant role. We calculate a marked shift in bremsstrahlung power density compared to beam power, from 0.05 - 0.28 (hot fusion) to $1.4 - 8.1 \times 10^{-10}$ for cold fusion (palladium Z = 42) and water (average Z = 8). The delivered x-ray beam dose (at 1 meter) decreases as the radiation dose (Grays) per coulomb drops from 3.1×10^{19} Grays (hot fusion) to $1.4\text{-}3.3 \times 10^{-4}$ Grays for cold fusion. These calculations are consistent with the relative absence of apparent ionizing emissions from cold fusion systems except for a few reports looking in the ~6 to 20 keV region.

Perhaps more importantly, the bremsstrahlung radiant power from cold fusion differs from hot fusion in that - because of the markedly lower temperature - most of the Bremsstrahlung radiant power in cold fusion systems is in the near-infrared region. The energy transfer in cold fusion systems via bremsstrahlung radiation is limited by the skin-depth which for palladium (9.25×10^6 mhos/meter), in the near infrared ($10^{13} - 6 \times 10^{14}$ Hz) ranges from 2.7 to 20.9 nanometers. One implication is effective containment of the radiant bremsstrahlung power, and its overlap with thermal and phonon processes.

Therefore, both because of the skin depth and bremsstrahlung power density, any leakage of fusion power from within cold fusion systems by bremsstrahlung is found to be much less important than for any conventional plasma or hot fusion system. One corollary is the lock-in of any cold fusion bremsstrahlung may have secondary effects upon the rates of the desired fusion reactions. Furthermore, a second corollary of this analysis of cold fusion bremsstrahlung indicates that because of the much lower levels of bremsstrahlung power emitted, isotopic fuels of higher atomic numbers may be useful in cold fusion systems.

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TABLE 1 - ANALYSIS OF BREMSSTRAHLUNG IN FUSION

	Temp [deg K]	Central Density [#/m3]	Brems. Peak [Angstroms]	X-ray Power Beam Power [nondimensional]		Irradiation Xray Dose (at 1 meter) [Gray = 100 rads]		Penetration Depth (TVL Pb) [meters]	Radiation Region	Energy [e*V]	Role in cold fusion
Hot Fusion	$1\text{-}2\times10^{8}$	$2\text{-}3\times10^{20}$	2.5×10^{-03}	0.28	lead	3.1×10^{19}		$\sim30\times10^{-3}$	Pair production region	$\sim5\times10^{6}$	
				0.05	aluminum			$6\text{-}65\times10^{-3}$	Compton region	0.3-1.5 MeV	
								0.2×10^{-3}	Photoelectric region	~50 keV	
Cold Fusion	~290 -373	$\sim5\times10^{22}$	0.3	1.3×10^{-3}	palladium	7.8×10^{13}	palladium			~40,000 (est.)	peak arcing
				2.3×10^{-4}	water (average)	3.3×10^{13}	water (average)				
			$2.5\times10^{+03}$	1.6×10^{-7}	palladium	$9.2\times10^{+2}$	palladium	$\sim7\times10^{-10}$	skin depth	5	applied electric field
				2.8×10^{-8}	water (average)	3.8×10^{2}	water (average)				
			$4.5\times10^{+5}$	8.1×10^{-10}	palladium	3.3×10^{-4}	palladium	$0.27\text{-}2.1\times10^{-8}$	skin depth	0.04	thermal energy
				1.4×10^{-10}	water (average)	1.4×10^{-4}	water (average)				

(*) characterized by HVL
(**) secondary to skin depth

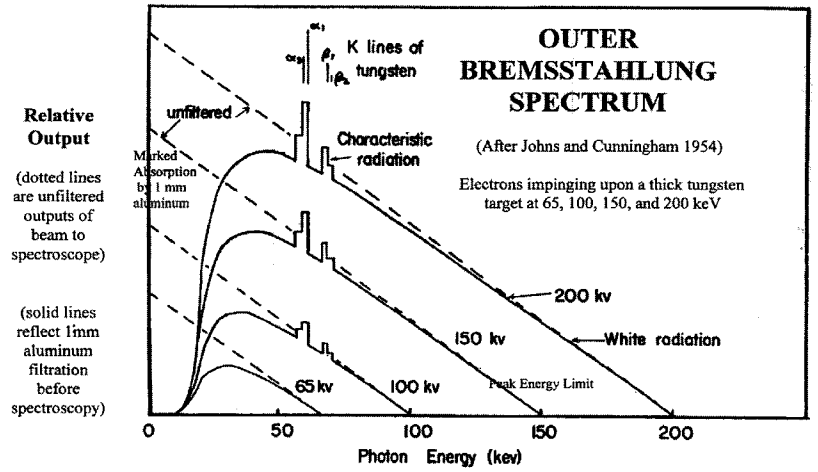

Figure 1 – Outer Bremsstrahlung Radiation Spectrum
Output bremsstahlung spectral curves which are continuous also contain characteristic material-specific photon peaks superimposed. There is not accuracy with respect to width of those characteristic peaks. Energy spectroscopy is of the bremsstrahlung emission from electrons of varying electrical accelerating potential which have impinged upon a thick tungsten target. The 'white' light radiation characteristics are shown, along with both unfiltered, and filtration using 1 millimeter of aluminum for beam hardening.

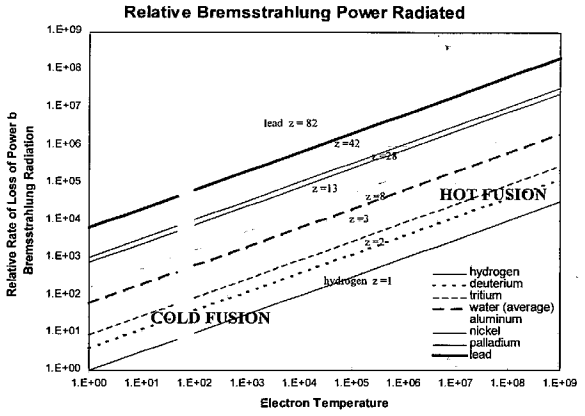

Figure 2 - Relative Bremsstrahlung Output Power Radiated
The standard calculation for plasma and hot fusion bremsstrahlung is used with corrections for electron temperature, and ion and electron densities is used to attempt to compare the relative bremsstrahlung power density for both hot and cold fusion. Various fuels (different atomic number as noted) are shown with the relative bremsstrahlung radiated power as a function of temperature.

TABLE OF SYMBOLS

B_q	Interaction parameter
c	speed of light [m/sec]
D	Dose delivered (Gray) at 1 meter from point of interest in beam
$dE_{rad}/dE_{collision}$	Relative loss of Energy to bremsstrahlung radiation to collisional losses for a beam [nondimensional]
dE_{rad}/dx	Energy loss per unit distance for a beam [joules/m]
e	electronic charge [coulombs]
h	Plancks constant
M	Target mass [kg/m^3]
m	Impinging particle mass [kg/m^3]
N	Number of fixed charges per unit thickness for a beam
n	number of ions [#/cm3]
P_{BR}	Heat loss from bremsstrahlung radiation [watts]
P_{CYC}	Heat loss from cyclotron radiation [watts]
P_{ENTH}	Heat loss from heat conduction [watts]
P_{OP}	Heat loss from optical radiation [watts]
P_{OTHER}	Heat loss from other routes [watts] (e.g. electrolysis gas stream)
P_{RAD}	Heat loss from all radiation components [watts]
T_e	electron temperature [degrees K]
v	velocity [m/sec]
V	applied voltage [volts]

Z	atomic number
ze	Charge on impact particle
Ze	Charge characterizing target material

Greek Symbols

χ_q	radiation cross section
ω	angular frequency [1/sec]
μ	magnetic permeability
η	x-ray power/beam power [nondimensional]
λ	correction for impact parameter [nondimensional]
$\delta_{skin\ depth}$	skin depth [meters]
λ_{min}	Minimum wavelength in the bremssstahlung output spectrum [meters]
σ	electrical conductivity [mho/m]