CLINTON LABORATORIES
CENTRAL FILES NUMBER
45-1-404

Cross file neutron

Date: January 31, 1945

To: R. S. Stone

From: L. B. Borst

Subject: The Neutrino

Copy #2 J. E. Wirth

Before reading this document, sign and date below

J E Wirth 2/7/45

CLASSIFICATION CANCELLED
DATE FEB 6 1959
Edgar J. Murphy
CO-ORDINATING ORGANIZATION DIRECTOR
OAK RIDGE NATIONAL LABORATORY
AUTHORITY DELEGATED BY AEC 9-10-57
EJM.

This document consists of 10 pages and 0 figures.
No. 2 of 19 copies. Series A.

~~SECRET~~

CLINTON LABORATORIES

January 31, 1945.

To R. S. Stone

From L. B. Borst

THE NEUTRINO

I have waited to write this memo until new data covering a penetrating radiation became available. These data have been reviewed with Drs. Kruger and Groetzinger at the University of Illinois and will be described in the latter part of this discussion.

Present Status of the Neutrino

The neutrino is a postulated particle emitted at the time of the disintegration of nucleus by electron or positron emission or by electron capture. The evidence for its existence is purely inferential, for there are no experiments which directly establish its existence. The various lines of reasoning upon which its existence is based are the following:

1. Beta rays (and positrons) from a single variety of radioactive nucleus are not emitted with a single energy, but show a continuous distribution of energy from zero to a given upper limit characteristic of the substance. The various nuclei presumably are identical before disintegration and again after disintegration. The average energy of the beta rays is about a third of the maximum energy.

2. Calorimetric measurements on pure beta sources show the energy degraded into heat to be identical to the average energy determined from the energy distribution measurements.

3. Disintegration energies determined by other means correspond to the maximum energy rather than the average. This was first observed in the natural radioactive series where branching sometimes occurs. The sums of the alpha and beta energies by either route are identical only if the maximum beta energy is used. The principle has been abundantly established in the field of artificial radioactivity where conservation of mass-energy may easily be checked.

4. Studies of the kinetics of beta emission indicate that the momentum of the system is not conserved if the beta particle and recoil nucleus only are considered.

The enumerated evidence lead us to believe that a beta disintegration involves the energy of the most energetic particle produced in the transition, but that an average beta ray will show only one-third of this amount. This discrepancy is fundamental and is thought to be accounted for by the emission of an unobserved particle capable of carrying away the missing energy and momentum.

The only alternative, considered at the present, is the abandonment of the laws of conservation of energy and momentum on an atomic scale.

Additional conservation principles of a less easily visualized nature, i.e. conservation of nuclear spin and statistics, must be discarded unless a neutrino having the proper attributes is emitted during the beta process.

The characteristics of the neutrino may be partially characterized by experiments conducted to establish its existence. The mass when at rest must be small compared to that of the electron. It must have no charge, and will penetrate matter producing few if any ions. It has attributes of spin and statistics. It will carry away its fraction of the momentum and energy of the system.

There has been no positive evidence for its existence, for no effect has been observed attributed to its interaction with matter. This interaction must, therefore, be extremely small under the conditions studied. The only processes which can be said to exist with certainty are those involving the reverse of the emission process. That is, if we postulate the production of a particle under given conditions, that particle must, under the proper circumstances, necessarily produce the reverse reaction in which it is absorbed. Such inverse processes may be calculated and prove to be unobservably small.

The existence of the neutrino is considered by most physicists as the best explanation of a group of fundamental experimental data. Under the assumption that it exists, an examination and evaluation of its possible physiological effects is in order. The only conclusion which can be drawn from their work is that such a hazard has not been found using the data and methods available.

## The Neutrino Problem

The existence of a health hazard due to the emission of neutrinos at Hanford must be considered as a distinct possibility. Attempts have been made by Wigner (CP-720) and Wollan (CP-1140) to evaluate such a hazard.

It has been estimated that about 15% of the energy associated with the fission event appears as beta and gamma radiation from the fission fragments. Approximately one-third of these is beta energy and two-thirds gamma energy.

Under the neutrino hypothesis twice the energy of the beta rays will go into neutrino energy. We are, therefore, confronted with the problem of a pile 10% of whose energy is emitted in an undetectable penetrating form. A pile with a 100 megawatt heat output will be a 10 megawatt neutrino source.

The only other source of similar magnitude is the sun. If its energy source is the carbon-nitrogen cycle, in which four hydrogen atoms are converted to an alpha particle (see H. A. Bethe Phys. Rev. 55, 434 (1939)), two positrons are liberated in the process together with two neutrinos. These neutrinos will escape from the sun without absorption if their only interaction is the inverse beta process. Assuming no absorption nor degradation, the energy flux at the earth's surface will be equivalent to that from a Hanford unit at a distance of about 20 feet.

The fact that biological species have developed on the earth's surface supports the conclusion that if these assumptions are valid, no hazard exists at Hanford.

The two sources differ in the amounts of shielding provided: A Hanford unit has at most 15 feet of shielding; the sun, 400,000 miles. If the cross section of the neutrino is as great as $10^{-33}$ cm$^2$ for degradation or absorption in the material of the sun, only 10% of those created will escape. In this case proximity to a Hanford unit would represent ten times the neutrino hazard of normal life. Assuming little absorption in the sun, no hazard exists at Hanford, but if absorption does occur in the sun ($\sigma > 10^{-33}$) one may not use it as a means of evaluating the hazard.

Wigner (CP-720) has discussed the various simple methods of neutrino interaction with matter. They are summarized here for convenience:

1. Inverse Beta Process. The inverse beta process already mentioned involves the absorption of a high energy neutrino by a nucleus, causing the immediate emission of a beta particle or positron. The resulting nucleus will frequently be radioactive and can be detected by this means. The cross section is estimated by Wheeler and Fermi to be $10^{-44}$cm$^2$, a value perhaps observable at Hanford, but constituting no hazard.

2. Elastic Collision with Electrons. The electron-neutrino interaction has been measured by M. E. Nahmias (Proc. Camb. Phil. Soc. 31, 99 (1935)) using a large radium source (with disintegration products) and heavy lead shielding. The cross section found is less than $10^{-31}$ cm$^2$ and, therefore, constitutes no hazard under Hanford conditions.

3. Elastic Collision with Nuclei. Elastic collisions of neutrinos with nuclei constitute the principle gap in our knowledge, and it is this effect which may constitute a hazard. If such a process occurs, it may be injurious to tissue without being easily detected. Our present methods of detection used for x-rays, radioactive materials, etc., show only the presence of charged or ionized particles. In these fields the methods have proved satisfactory because there is nearly always the dislocation or ionization of electrons, and these secondaries are directly observed.

The present process differs from most atomic processes in that the production of ion pairs may be the rare rather than the common event. This situation exists since the mass of the neutrino is small in comparison to the mass of the nucleus, and the energy imparted to the nucleus is moderately small. To produce ionization of the atom or molecule, the nucleus must literally run away from its least tightly bound electron. The energy of abandonment of this electron is expressed by the following equation:

$$E = \frac{1}{2} m_e \left(\frac{2 h\nu}{Mc}\right)^2$$

where $E$ = abandonment energy of electron

$m_e$ = mass of electron

$h\nu$ = energy of neutrino (assuming negligible rest mass)

$M$ = mass of recoil nucleus

$c$ = velocity of light.

If this value exceeds the ionization potential of the element or molecule, the electron will be left and an ion pair formed.

The most favorable case for observing this event is hydrogen which has a low mass and a moderate ionization potential. The most energetic neutrinos from Ra-C striking a hydrogen atom and bouncing back the way they came give an energy of 11.6 ev whereas the ionization potential of hydrogen is 13.58. While this should theoretically not produce ionization, a considerable fraction of the ejected hydrogen atoms would probably be found to be charged. The production of hydrogen ions by neutrinos from the Clinton pile has been studied by Wollan (CP-1140). The cross section for hydrogen ion production is less than $5 \times 10^{-31}$ cm$^2$. In this work the shield was considered to have no effect on the neutrinos. This value of the cross section does not correspond under Hanford conditions to a serious hazard.

The interaction of neutrinos with atoms without the production of ionized particles is the great unknown. There is no knowledge of this type of event, neither the magnitude nor the physiological consequences.

Heretofore there has been no reason for the medical profession to investigate the bodily damage brought about by the production of molecular fragments, free radicals, and unattached atoms. Physiological reactions involve hydrolysis, oxidation or reduction ionic dissociation and polymerizatio of organic molecules. These reactions give rise to conventional compounds which are used or eliminated by the organism. The production of molecular fr ments does not occur in normal life processes, and consequently has played no important role in physiology. These fragments presumably are formed during radiation therapy, but are accompanied by ionized particles much more easily measured. The effects caused by their presence are, therefore, all lumped un the measurable constituent, ionization, and have not been distinguished from it. These fragments as well as ionized particles will produce abnormal physi logical reactions, the products of which are presumably poisons.

Possible methods for the production of such molecular fragments are few and undeveloped. Thermal dissociation produces molecular fragments, but rarely occurs in a living organism. Fragments may also be produced by the elastic scattering of epi-thermal neutrons; neutrons above the thermal region and not easily measured by thermal detectors but below the region where recoil protons produce appreciable ionization. A third method may be used which consists of the impregnation of tissue with a radioactive substance undergoing K electron capture or an isomeric transition. Molecules containing such an atom are disrupted by the nuclear transition and show unusual chemical reactions.

Perhaps the only assumption that can be made is that fragments, atoms and radicals have the same physiological effect as ions. There is no experimental evidence to support this postulate, but no better guess can be made. The particles will not be found in clusters or tracks and can only be considered analogous to gamma rays. The tolerance limit would then be placed at $1.6 \times 10^{11}$ particles per day per gram of body tissue.

From this assumption a critical cross section may be calculated. The neutrino production in a 250 megawatt plant is $3.5 \times 10^{18}$ $\nu$/sec. If the cross section of the neutrino process is less than $2 \times 10^{-29}$, a tolerance dose will not have been exceeded in an eight hour day. No assertion may be made as to whether the actual interaction is large or small compared to this quantity.

There is reason to believe that the cross section will vary in a regular manner as a function of atomic weight, atomic number, etc., based on our present theory. One might expect that large values would be found for large nuclei, but this need not necessarily be true. The best analogy that can be drawn is that of thermal neutron scattering. While values of scattering cross sections are not easily obtained there seems to be evidence that those for adjacent elements may differ widely. In the case of the neutrino this might also be true. At the present it would be totally unwarranted to assume that because the elastic cross section of one nucleus is small, those of others would be similar. The only safe procedure would be to determine the value for biologically important elements.

If the same cross section is assumed for several nuclei, the probability of their being liberated from the chemical compound will decrease with increasing weight. This is purely an energy consideration, for a heavy nucleus will be given a smaller recoil energy than a light one for the same neutrino energy. The best chance of observation will be hydrogen, and Wollan has already studied it. Assumptions were necessary to estimate the number of hydrogen atoms per hydrogen ion. This ratio would appear to be about 10 to 1. Upon this basis the effect due to hydrogen ($\sigma = 2.5 \times 10^{-30}$) appears not to be dangerous. A more direct experimental check of this element is definitely in order.

Other biologically important elements are carbon nitrogen and oxygen. Presumably other elements occur in sufficiently small concentrations as to be unimportant. The determination of the reaction in these elements is probably out of the range of experimental possibility at the present time.

## Experimental Detection of Neutrino

The search for the inverse beta process appears to be an extremely difficult, if not impossible, undertaking. It has primarily theoretical interest, for this process can never be a menace to health. This process, however, is the only sure way to successful observation, however difficult. To establish definitely the existence of the neutrino by this method would be of extreme importance, for upon the basis of successful observation, the alternative interactions might better be determined.

One possible method is to subject rubidium to the neutrinos from the Hanford pile or storage reservoir. $Rb^{85}$ upon absorption of a neutrino would emit a beta ray to become $Sr^{85}(T_{\frac{1}{2}} = 60d)$. The strontium so produced could then be extracted and the induced radioactivity measured. The sensitivity of this method would probably not be adequate to permit the observation of a cross section of $10^{-44}$ $cm^2$. It might, however, be possible to observe a cross section of $10^{-40}$.

Electron interaction or nuclear interaction producing charged particles has been studied sufficiently to demonstrate the absence of a health hazard. This interaction is implicitly measured during ordinary surveys. These surveys have shown no penetrating radiation of a magnitude approaching tolerance.

The study of nuclear collision without ionization stands as the most important and perhaps most difficult process to measure. This is due primarily to the lack of a sensitive detector of atoms and free radicals. All previous work with such species has been conducted under circumstances where the flux of the particles was controlable and could be raised to a level easily measured. Most methods used require the reaction of number of molecules visually observable. This is true of work with free radicals where a metallic film is deposited or the physical characteristics (eg. magnetic susceptibility) of the substance is changed. Such methods are far too crude for the present job.

Conversations have been held with Messrs. Phipps and Simpson at the Metallurgical Laboratory during which several possible methods were suggested. The problem under discussion at that time was the hydrogen interaction exclusively.

Only one method of detecting hydrogen atoms in small numbers has proved satisfactory experimentally. That is the partial reduction of freshly prepared molybdenum oxide. This oxide, yellow in color, is reduced by hydrogen atoms to a blue suboxide of some sort. The reaction seems to be nearly specific for hydrogen atoms, and, by ordinary standards, is quite sensitive. The reaction might be used as the basis for several methods of detection. The oxide might be placed adjacent to a paraffin block and exposed to neutrinos. The recoil hydrogen atoms from the paraffin would reduce the oxide. Quantitatively this method lacks greatly in sensitivity. A somewhat more satisfactory method rests on the observation of Phipps, that hydrogen atoms are absorbed and held by de Kotinsky cement (a laboratory high vacuum cement) and are later liberated upon heating. By this method it might be possible to utilize the hydrogen atoms formed in grams or pounds of cement. Under Hanford conditions this might come within a factor of 10 or 100 of showing a tolerance dose. The method would require development and quantitative study.

A possible method of observation is by measuring the changes in electrical characteristics of an oxidized tungsten surface due to the removal of oxide by the atoms. Such a method is logically possible, but would require extensive development.

Mr. Simpson suggested that while the study in hydrogen was extremely difficult, the measurement of such an effect in lithium might well be possible. His suggested method consisted of collecting the recoil nuclei from an extended area of lithium metal upon a filament. Upon heating the filament, the lithium atoms are thermally ionized and evaporate as ions. Using a suitable potential to a collecting electrode and measuring this current by an amplifier circuit, it should be possible to measure a cross section of $10^{-30}$ $cm^2$.

While such an experiment might not give direct information concerning physiology, it appears to be the most practical approach. If an effect of appreciable magnitude were found, then intensive investigation would be in order; if it were possible to restrict the cross section to less than say $10^{-33}$, the reaction in other elements would presumably not constitute a hazard.

No suggestions can be made at the present time of feasible experimental methods for detecting uncharged recoil atoms in carbon, nitrogen or oxygen.

Other Penetrating Radiations

The neutrino has received emphasis as a possible hazard due to its inferential existence and abundance. Other previously unknown radiations are, of course, always possible. Radiation surveys are probably adequate to determine the existence of a hazard if the interaction produces appreciable ionization. It is, of course, always possible to assume radiations the destructive properties of which we do not understand. This would be, however, a fruitless search -- looking for an unknown effect of an unknown radiation.

The energy of the fission event is such as to make the production of mesotrons possible, though not probable. Charged mesotrons from fission would be no hazard, since they could have little kinetic energy and small penetrating power. A neutral mesotron would have high penetrating power and might be hazardous through the mechanism of non-ionizing collision.

During the last two months there have been rumors of a new penetrating radiation observed at the University of Illinois Cyclotron. Since this radiation seemed relevant, I reviewed the work with the experimenters, Drs. Kruger and Groetzinger. A summary of the known properties of the radiation is reviewed below.

1. The radiation is associated with the 10 MV deuteron beam of a cyclotron and is observed through five feet of water and 1 foot of lead. It must, therefore, consist of uncharged particles, not gamma rays and presumably not neutrons.

2. It produces ionizing secondary particles, presumably electrons, which have energies up to 8 MV. These secondaries consist of one particle per event or two particles traveling in opposite directions. This process must presumably not be a scattering process.

3. The secondaries show no orientation effect, so the kinetic energy of the primary must be small compared to the energy liberated in producing secondaries.

4. The small yield of primaries is independent (within experimental error) of the target material.

This evidence is believed by the experimenters to indicate the producti[on] of light neutral mesotrons of mass about 20 electrons which undergo spontaneou[s] disintegration into electron pairs. Using this interpretation and the half life of the mesotron ($10^{-6}$ sec), one may estimate that one particle is produce[d] per $10^{10}$ deuterons.

Light mesotrons have been reported as a component of cosmic rays by Dr. Schein at the University of Chicago. Very little is known about them, but if they exist they are possible products of fission. Nobody knows how they are produced or what their properties are. They must, therefore, be looked for in connection with pile radiations.

Dr. K. Z. Morgan has undertaken a search, but at the present time is unable to report definitely the presence of such a penetrating radiation. He has been able to show that if it is a component of pile radiation, no hazard exists from ionization due to secondaries.

The properties of this particle are similar to the neutrino in that it carries no charge, has a comparable kinetic mass, and has only a small interaction with matter. Arguments concerning elastic collision without ionization apply here as well as to the neutrino.

Recommendations

The previous material has sketched our present knowledge concerning penetrating radiations, showing where our knowledge is incomplete. To attempt to fill all such gaps would be prohibitively costly, yet to ignore the possibl[e] hazards is not wise. The reasonable course is to access the most important points and to base further action upon information gained.

The most significant point appears to me to be the physiological effect[s] of uncharged molecular fragments. These are formed by epithermal neutrons, an[d] may be produced by neutrinos and light mesotrons. If the tolerance dose were larger than for charged particles, the neutrino problem would become less important by virtue of this fact.

Dr. Nordheim feels that if a cross section of $10^{-40}$ cms is experimentally detectable, the inverse beta process should be investigated. This is not based upon a health hazard, but rather that positive results would greatly increase our knowledge and understanding of the whole problem.

A search for lithium atoms produced by elastic scattering of neutrinos appears to be the most satisfactory approach to the scattering without ionization problem. It seems less important than the establishment of a tolerance.

Work should be continued to evaluate the importance of light mesotron production.

## Summary

The existence of a neutral particle of small mass (called the neutrino) is required by experimental evidence related to beta decay. The best present alternative requires the abandonment on an atomic scale of the laws of conservation of mass, energy and momentum.

The Hanford pile, in its vicinity, rivals the sun as a neutrino source. Cross sections of interest less than $10^{-33}$ cm$^2$ are thereby ruled out.

Possible neutrino interactions are threefold:

1. The inverse beta process involves the absorption of a neutrino and emission of a positive or negative electron. Predicted cross section $10^{-44}$ cm$^2$.

2. Elastic collision with orbital electrons. Cross section $< 10^{-31}$ cm$^2$.

3. Elastic collision with nuclei.

   a. Resulting in ionization. Cross section in hydrogen $< 5 \times 10^{-31}$ cm$^2$

   b. Resulting in uncharged atoms, radicals, etc. No data known. Assuming physiological effects equivalent to ions, a cross section greater than $2 \times 10^{-29}$ would exceed tolerance. Experiments on hydrogen indicate this to be less than $2.5 \times 10^{-30}$ cm$^2$.

Experiments to evaluate these effects are exceedingly difficult.

1. A cross section of $10^{-40}$ for the inverse beta process might be achieved.

2. A cross section of $10^{-27}$ for hydrogen atom production might be measured. A cross section of $10^{-29}$ for lithium atoms should be possible. No possible experimental methods are known for carbon nitrogen and oxygen.

Copies to: R. S. Stone
J. E. Wirth
E. O. Wollan
A. H. Snell
E. P. Wigner
R. L. Doan
K. Z. Morgan
S. K. Allison
L. W. Nordheim
L. B. Borst
Reading File
Central File (8)

L.B. Borst

L. B. BORST

~~SECRET~~