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# Fuzziness in Radiation Protection and Nuclear Safety

# (Human Factors and Reliability)

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ABSTRACT: In radiation protection and nuclear safety, there are many uncertainties or fuzziness due to subjective human judgement. It is desirable to have a theory by which both non-probabilistic uncertainties, or fuzziness, of human factors and the probabilistic properties of machines can be treated consistently. Fuzzy set theory seems to be an effective tool for analyzing the risk and safety of complex man-machine systems such as nuclear power plants.

## I. Fuzziness in Radiation Protection and Nuclear Safety.

The uncertainties under emergency conditions, in particular, the uncertainties in estimating dose-effect relationships in Hiroshima and Nagasaki have been repeatedly discussed by Professor Nishiwaki since the first meeting on the medical and pathological effects of atomic bombings held at the Department of Pathology of the late Professor Ryojun Kinoshita, the then Professor of Pathology, Faculty of Medicine of Osaka University in 1945.

The survivors and those who visited Hiroshima immediately after the atomic bombing could have been subjected to a number of other possible noxious effects in addition to atomic radiation. Hospitals, laboratories, drugstores, chemists, pharmaceutical works, storehouses of chemicals, factories etc. that were situated close to the hypocentre were all completely destroyed and various mutagenic, carcinogenic or teratogenic substances must have been released. There was no medical care and no food in the region of high dose exposure and the drinking water was contaminated. There would have been various possibilities of infection. Mental stress would also have been much higher in the survivors closer to the hypocentre. It is confusing which factor played a dominant role. In addition, there would be problems in accurately recording the position of the exposed persons at the time of the atomic bombing and also in estimating the shielding factors. There may be considerable uncertainty in human memory under such conditions. It is also possible that there could have been a large storage of gasoline to be used for transportation of the army corps in Hiroshima. Therefore, there is a possibility that various toxic substances, mutagenic or carcinogenic agents such as benzopyrene and other radiomimetic substances could have been released from various facilities destroyed at the time of the atomic bombing.

In exploding an atomic bomb, in addition to ionizing radiation, strong non-ionizing radiations, such as infrared, ultraviolet light, visible light, electromagnetic pulse radiations, as well as heat and shock waves are produced. Therefore, the possibility of the combined effects of all these direct factors and the indirect factors such as those mentioned above must be considered in interpreting the effect of the atomic bombing, instead of ascribing all the effects solely to ionizing radiation.

In the case of the Bikini accident, a Japanese fishing boat was showered by strongly radioactive ash from hydrogen bomb testing whilst engaged in fishing in the Bikini area on March 1, 1954 at

TABLE 1. Level of consciousness and error potential

| Phase | EEG | Consciousness | Power of attention | Physiological condition | Error potential |
|---|---|---|---|---|---|
| 0 | Delta | Unconscious, coma | Zero | Deep sleep, brain paroxysm | – |
| I | Theta | Sub-normal, subconscious | Inactive | Fatigue, monotony, doze, drunken | +++ |
| II | Alpha (eyes closed) | Normal, relaxed | Passive | Awake, resting, introvert, routine normal work | +~++ |
| III | Beta | Normal, clear | Active | Active work, alert, awake, good attention, prediction of danger possible | Minimum |
| IV | Strong beta or epileptic | Hypernormal, excited | Fixed at one point, judgement stops | Emergency defence reaction, sudden fear, consternation, panic | Maximum |

about 150 km from the test site. When the ship came back two weeks later, stronger radioactivity was found in such easily movable things as dust, gloves, ropes and clothing rather than on the smooth surface of the ship. Therefore, the exact dose of a particular person was difficult to estimate, although the range of probable gamma external dose was estimated to be about 170 to 600 rad. The degree of uncertainty was considered far greater for internal dose estimation. The long-lived radionuclides detected many weeks later in organs such as the liver, could not be considered the only sources of internal exposure. Depending on the assumed degree of initial incorporation of short-lived radionuclides, a wide range of estimates was possible (10 to $10^4$ rad).

When the Three Mile Island accident occurred it was 04:00 hours, a time when the error potential of operators would have been very high. When the Chernobyl accident occurred it was 01:23 hours. This is a time when the level of consciousness is about to drop and the error potential begins to increase. Table 1 gives levels of consciousness and error potential. Fig. 1 shows frequency of accidents and level of arousal indicated by Critical Flicker Frequency, CFF. When flickering appears, the test person is supposed to press the button. This value drops at low level of arousal. Fig. 2 shows normal EEG.

In regard to the comparison of the Chernobyl contaminated area, Hiroshima and Nagasaki, there would be a high degree of uncertainty. During the initial period, when the resistance of the body is reduced after irradiation, various types of opportunistic infections would be possible. Under these circumstances there are many doubtful cases and one may not be able to say that it is <u>not</u> due to radiation. To describe these situations, what is needed is not the 'yes' or 'no' judgement by ordinary binary logic "0" or "1", but the fuzzy logic which allows the degree of expert judgement between "0" and "1". [5-15]

## II. Human Factors and Reliability

The response of the human brain to different types of noises and signals may vary somewhat for different individuals and for different groups of people. In Fig. 3 Tsunoda's method of key-tapping test on the dominance of cerebral hemispheres for different voices, sounds or tones for different people is shown. The test is based on dichotic competition between tones synchronous with a subject's key-tapping in one ear and delayed tones in the other ear. The left ear dominance for a tone indicates the underlying right brain dominance for the same tone and, inversely, the right ear dominance means the left brain dominance, because the auditory nerves are dominantly connected to the contralateral cerebral hemispheres.

Human reliability may be affected by various factors, physical, psychological, physiological, environmental, etc.: fatigue, stress, learning, experience, personality, preference, level of consciousness, degree of responsibility, type and quality of work, degree of comfort, chance phenomena, etc. All these numerous factors may influence directly or indirectly human reliability and performance. The reliability of detection of trouble is low when the amount of information is too little, because of too much guess work. With an increase in information, the reliability may increase to a certain level, but with excess information, confusion may arise and the reliability may drop. The reliability of judgement may increase with the increase in tension or level of consciousness. However, with too much tension the reliability may drop at the hypernormal excited state. The reliability of work may increase with experience. However, with too much experience carelessness may set in and the reliability may drop occasionally, but in general it increases with experience. The reliability of operation may decrease with the increase in stress and complexity of work. Too simple and monotonous work may decrease the reliability. However, proper feedback of operational results may increase reliability. It is doubtful whether these complex factors affecting human reliability could be adequately represented by probability. [1-33]

III. Conclusion

In risk analysis or risk assessment we encounter a variety of sources of uncertainties which are due to fuzziness in our cognition or perception of objects. For systematic treatment of this type of uncertainty, the concepts of fuzzy sets or fuzzy measures could be applied to

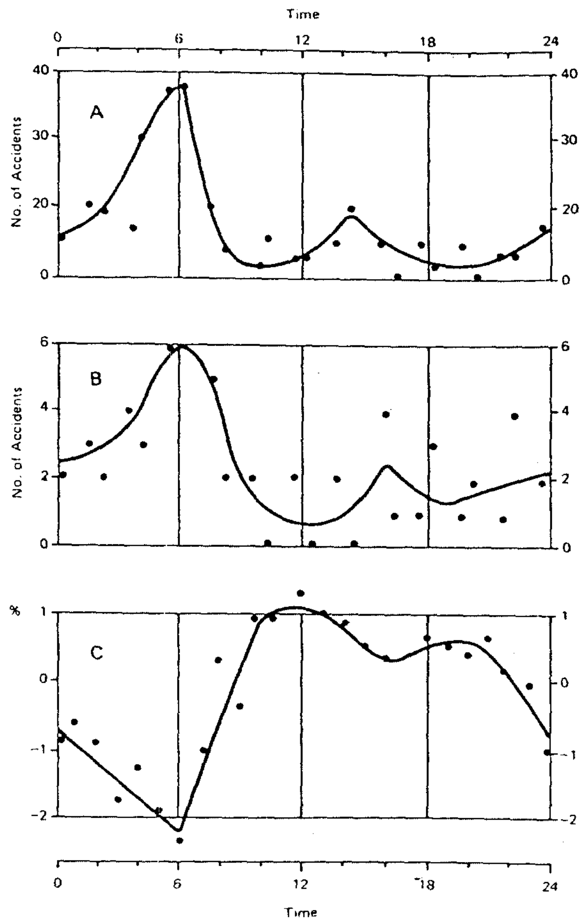


FIG. 1. Flicker Value (CFF) and frequency of accidents in Japan.

A: Car accidents caused by drivers falling asleep (Tomei Highway between Tokyo and Nagoya, 1965).

B: Train accidents on national railways due to violation of traffic signals (1926-1960).

C: Flicker Value (CFF) indicating level of arousal. The diurnal cycle was estimated by an experiment in which the working hours are shifted by 3 hours each day. Thus, after 8 days, the working hours return to the original. When the flickering frequency of the test light is increased, the flickering may disappear at a certain frequency, Critical Fusion Frequency. If the frequency is reduced, the flickering appears at a certain frequency, Critical Flicker Frequency. This is referred to as CFF.

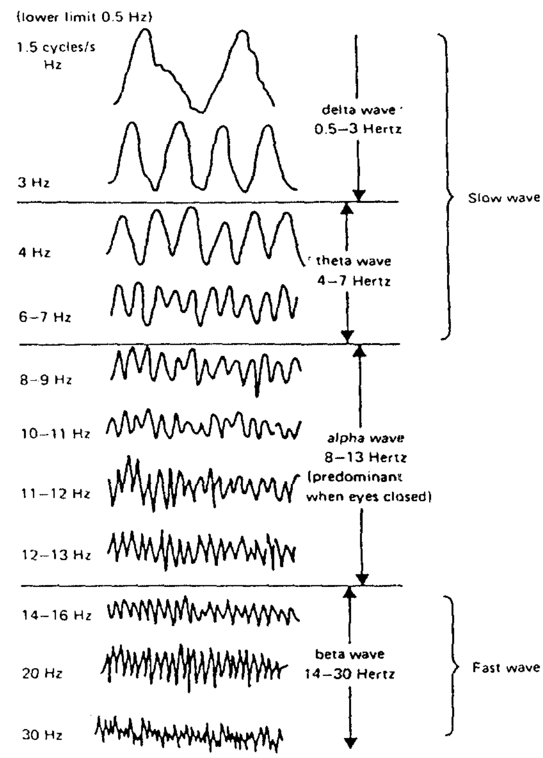


FIG. 2. Normal EEG or electroencephalogramic pattern

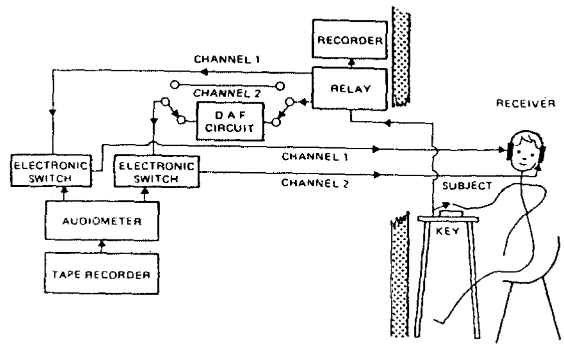


FIG. 3. Test method for cerebral dominance (Tsunoda)

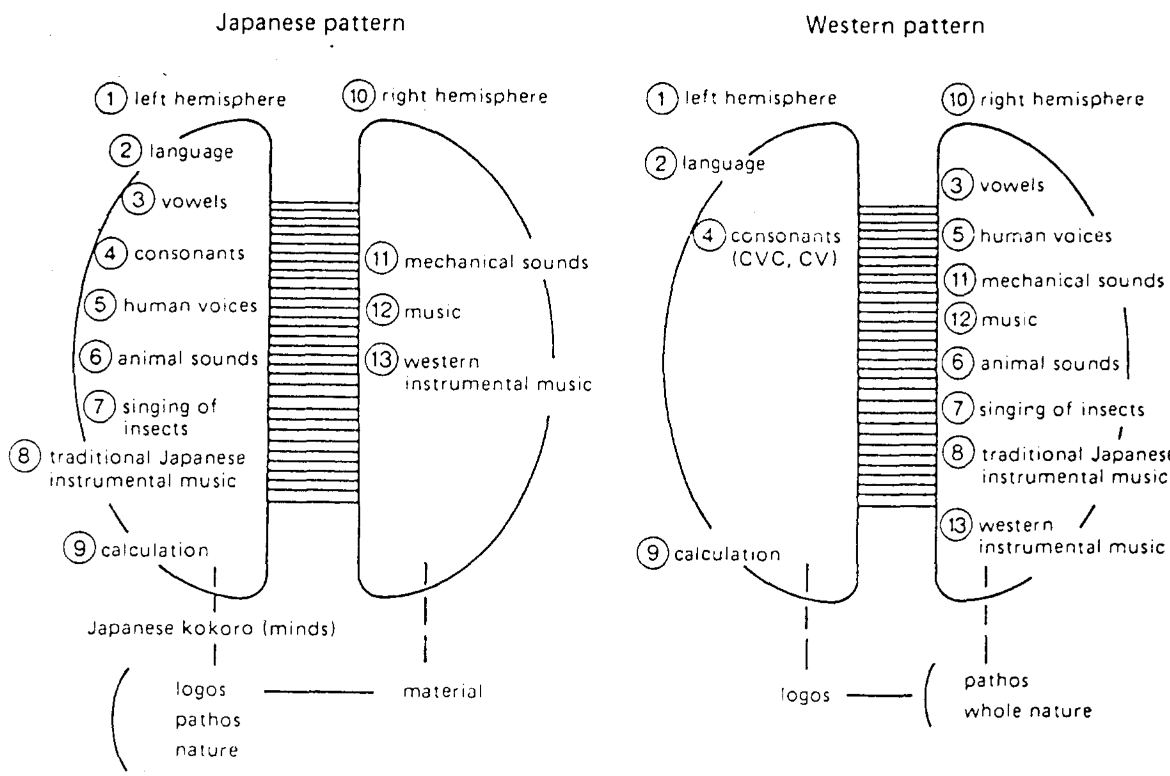


FIG. 4. Difference in dominance of left (verbal) cerebral hemisphere and right (non-verbal) cerebral hemisphere for different types of sounds between Japanese and Westerners. Much wider range of sounds seems to be treated by the verbal hemisphere in the case of Japanese.

construct system models, which may take into consideration such fuzziness. From the cognition or perception point of view, fuzziness may be divided into two; subjective fuzziness on the part of the man receiving information and objective fuzziness on the part of the object or incoming information. Conventional probabilistic approach alone can not take care of all these fuzziness consistently.

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