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The potential for disease initiation by inhaled beta-emitting nuclear particles

Norman O. Aamodt[1]

Abd Consultant, 517 Bear Cub Lane, Lake Placid, NY 12946, United States

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ABSTRACT

There were many anecdotal reports of injuries to humans, animals and plants following the Three Mile Island, Chernobyl and Fukushima accidents that were indicative of radiation exposures that delivered a dose of at least 0.5 Sieverts, but studies that attempted to relate observed increases of cancer rates and other injuries with exposure to the radioactive releases from these accidents have failed to find an association.

To resolve this dissonance, it was assumed that an analysis of knowledge about accident releases and health effects gathered from one of these accidents could lead to the identification of an unrecognized exposure that could be inferred to have caused a specific observed injury that required a dose of at least 0.5 Sieverts. Because there is considerably more useful knowledge of reactor releases of radionuclides and observed health effects related to the Three Mile Island accident, that knowledge is analyzed.

A relationship is inferred to exist between exposure to particulates in plumes released from the station vent stack and severe prolonged immunosuppression, a known effect of an exposure that delivers a dose of at least 0.5 Sieverts. More than ninety percent of the particulates were comprised of Strontium 89 nuclides, essentially pure beta emitters. Because Strontium is a metal, the nuclides in the particulates were configured as stable crystals which, when coming to rest in body tissue, functioned as intense point sources of chronic beta irradiation.

The inference led to the hypothesis “particulates comprised of Strontium 89 nuclides provided the exposure that caused the health effects that were observed following the Three Mile Island accident”. The hypothesis was tested for validity against two requirements; that only the humans beneath the plumes, who would have inhaled the particulates, expressed the abrupt and persistent rise in the health parameter Deaths from all Causes that would result from the severe prolonged immunosuppression that follows a 0.5 Sievert dose, and that they expressed the excess cancers that would be expected following organ doses of 0.5 or more Sieverts. These effects were found. The Hypothesis is therefore valid and leads to knowledge of the heretofore unknown mechanisms and effects of low LET beta irradiation by a particulate.

Background

This study was conceived in response to a fundamental rule in epidemiology: “Absence of evidence of an effect does not constitute evidence of absence of that effect” [1]. That “rule” is instructive; it challenges the data on which an investigator relied to find that a relationship does not exist between an observed injury and the radiation exposure that was assumed to have caused it. Failure to accept that challenge has caused the bafflement of investigators and has vexed populations at risk. As examples, studies that attempted to link assumed routine reactor emissions with excess cancers among nearby children and studies that attempted to link Chernobyl, Fukushima and TMI accident emissions with cancers and other diseases found the assumed exposures inadequate to cause the observed effects [2,10,20,21]. In these examples, the “rule” challenges the relevance of the assumed exposures, a challenge that has not yet been met, often because the investigator lacked access to the science (“knowledge”) required to challenge the validity of the assumed exposure. This study is a response to the “rule”.

Introduction

Reports of injuries to residents, domestic animals, birds, plants and insects that followed the Three Mile Island (TMI) accident were dismissed on the assumption that the official estimates of exposures to the surrounding population were correct, that the only significant exposure

E-mail address: normanaamodt@aol.com.
[1] Retired.

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was to the gamma radiation of noble gasses from which no resident received a dose that exceeded 0.001 Sievert (Sv) [3,4].

The 0.001 Sv maximum exposure attributed to TMI accident releases of radionuclides received credibility by an order issued by the Nuclear Regulatory Commission (NRC). Before the undamaged Unit 1 reactor could be restarted, the NRC was required by the Atomic Energy Act and NRC regulations to determine that the accident was not an Extra Ordinary Nuclear Occurrence (ENO). Following consideration of a Staff report on accident consequences [5], the Commissioners concluded that significant releases were limited to the noble gasses which delivered no dose in excess of 0.001 Sv, that no person in the surrounding population was injured and the accident was therefore not an ENO [6].

In succeeding years four studies were reported that challenge the ENO finding that TMI exposures did not exceed 0.001 Sv. In 1984, in the NRC TMI Unit 1 restart proceeding to define issues required to be resolved prior to restart of the undamaged Unit 1 reactor, a party presented a request for follow up of her study of health effects observed within ten miles of TMI [7]. The study reported the results of her survey of the populations of three noncontiguous hilltop communities where residents experienced acute deterministic effects of exposure (erythema, epilation, nausea, anxiety, etc.) the first days of the accident. Among a variety of persisting effects, she found that of 19 births 11 had adverse outcomes and that the cancer mortality rate in the five post-accident years was 6.5 times higher than the historical average for the region, a potential effect of severe immunosuppression, an effect that would result from an exposure that delivered a dose to the blood of 0.5 Sv [8]. Persisting injuries to several varieties of garden plants were also found, that demonstrated reliable indications of exposures that delivered doses of more than 0.3 Sieverts (N1). The NRC did not conduct a follow up study.

In 1985 researchers from the Uniformed Services University found that a group of local residents who experienced persistent anxiety suffered severe reduction of lymphocyte populations, a cause of severe persistent immunosuppression, that they noted is a result of a 1.5 Sv dose to the blood (8). In 1996 researchers from the Russian Academies of Science studied blood samples drawn from sixteen TMI area residents who had experienced acute symptoms of exposure at the time of the accident. They found that those residents still suffered severe immunosuppression and that their exposures delivered doses of 0.6–0.9 Sv to their blood [9].

In 1991 researchers from Columbia University reported a study that tested the hypothesis “risks of specified cancers may have been raised by exposure to radiation emanating from the Three Mile Island nuclear power plant” [10]. Their exposure model expressed gamma dose level in relative terms because of uncertainties resulting from the small number of dosimeters (tld’s) in place at the time of the accident and the fact that the vent stack monitor of noble gas releases went off scale in the early hours of the accident. Correlation of increases of cancer incidence with relative gamma dose was insufficient to find a convincing relationship. However, the population did express an excess of incident cancers of thirty percent over the study period, 1979–1985 [10,11]. The expression of cancers after exceedingly shortened latency periods is indicative of the severe immunosuppression observed among TMI residents, a consequence of a dose of 0.5 or more Sieverts to the blood.

The findings of these four studies are consistent; they describe effects of an exposure that delivered a dose of more than 0.5 Sieverts, a dose five hundred times greater than the dose that was postulated by the NRC and that was generally assumed to be correct.

Analysis

Potential exposures

An exposure that could deliver a dose of 0.5 Sv is suggested in a report by the NRC Office of Inspection and Enforcement [12]. About 7:50 AM the morning of the accident the vent stack exhaust monitors of noble gas, Iodine and particulate releases all alarmed as maximum allowable levels were reached, rose several orders of magnitude to go off scale shortly after 8 AM and remained off scale for nearly three days. No existing evidence suggests that gamma emissions from the noble gases or from Iodine nuclides injured residents surrounding the TMI facility. No evidence has yet been developed to determine whether any health effects resulted from exposure to emissions from the potentially hazardous particulates (N2) that were also released, far above allowable levels, from the 145-meter-high vent stack.

The function of the vent stack, like that of any “smoke stack”, is to eject pollutants high above the facility to be carried away by the wind. Therefore, the tld’s around TMI measured the dose delivered by the highly-attenuated gamma rays that reached the ground. The doses that these rays delivered were not harmful except, perhaps, where plumes were brought to earth during atmospheric inversions. The Iodines would deliver substantial doses where they were absorbed in rainfall. The particulates, comprised of beta-emitting nuclides [12], would fall to earth to be deposited on, inhaled and otherwise ingested by populations beneath the plumes and deliver potentially lethal beta doses to cells and DNA in tissues wherever they came to reside.

The beta “ray” is a charged electron that exhibits relatively high Linear Energy Transfer (LET) (N3). When it impacts matter in its linear path in the human body, it readily transfers its energy to that matter. In contrast, the gamma “ray” is a photon that exhibits low Linear Energy Transfer. When a human body is exposed to a field of gamma radiation, about 70 percent of the penetrating photons transfer none of their energy to body tissues. In contrast, when a particulate comprised of beta-emitting nuclides comes to rest in body tissue, the energy of all the electrons emitted by the nuclides in the particulate is absorbed in tissues within inches [13,14] to deliver a potentially lethal chronic dose to DNA and cells in the tissues surrounding it.

Relevant high LET nuclides

Measurements of plume radioactivity directly over the vent stack the first three days of the accident found that the ratio of beta to gamma radiation activity was more than seven to one [16]. The plumes, therefore, were comprised of a dominant quantity of essentially purely beta-emitting nuclides. The principal beta-emitting nuclides can readily be identified.

When the Zirconium fuel rod cladding melted early in the accident, allowing the release of nuclides from the fuel, the volatile gases and Iodines entered the core volume of pressurized water and steam and, in part, were released from the vent stack as plume components. The beta to gamma ratio of this mix of nuclides was less than 2. Most of the significant high LET fuel components remained solid or molten and were not released in significant quantities. However, Cesium and Strontium were boiling. Their nuclides entered the core volume and coalesced to form particulates that were released as plume components. More than 90% of this release consisted of particulates comprised of Strontium 89 nuclides, as indicated by averaging the TMI core inventories at shutdown calculated by the LOR-2, ORNL, Heidelberg and the Draft PEIS programs [15]. Strontium 89 emissions are more than 99 percent high LET beta “rays” and, because they emit essentially no gamma radiation [16], they were not detected.

Cerium and Ruthenium, the remaining beta-emitting elements whose nuclides might have been released to form particulates, were not released in significant quantities. They boil at 1600 and 2300 degrees Kelvin (K), respectively, above the melting point of the fuel rod cladding. Further, analysis of the damaged core resulted in the finding that “much of the fuel remained at fairly low temperatures (< 2000 K) and was exposed to high temperatures for only a short time” and that the twenty percent of the core mass that was in the molten zone was encapsulated in a crust [17].