Response to Bahadori

Dear Editors:

I want to thank A.A. Bahadori for sharing his views on the HPS "History of the LNT Model" video documentary. It's good to know that he watched all the videos with interest to see what new scientific data were available to refute the use of the LNT model. I wish to remind readers that this is a historical documentary of how the US came to accept and incorporate the LNT model into radiation protection guidance, policies, and regulations; it was not to refute or support the scientific validity of the LNT model. That said, Calabrese shares several new pieces of scientific information that many may not have known. These include:

1. The scientific underpinnings of the origins of the LNT model and how Muller irradiated fruit flies with a dose rate of about 100,000,000 times background radiation and then extrapolated potential effects down to zero, over eight orders of magnitude beyond the data. A full explanation of how this value was derived is provided by Calabrese (2019c). [Episode 2];
2. The fact that the original paper published by Muller concluded he had induced gene mutation using x rays but did not include any data, so his study could not be verified by others. [Episode 4];
3. Scientific challenges to Muller's gene mutation conclusion by a future Nobel Prize winner, Barbara McClintock, and Lewis Stadler suggested Muller had produced major holes (e.g., modest to large gene deletions) in chromosomes instead of gene mutations [Episode 5], which was later proven correct;
4. Muller's failed efforts to validate the LNT model by comparing the effects between the same dose delivered acutely vs. chronically (e.g., dose vs. dose-rate) and expecting the same outcome as predicted by the LNT model. [Episodes 5, 6, 7, and 8];
5. Before his Nobel Prize speech, Muller was aware that results from the chronic studies of Caspari didn't produce the same results as expected from the acute exposures of Spenser; yet Muller states in his speech that there is *"no escape from the conclusion that there is no threshold dose…"*. [Episodes 6 and 8];
6. Reliance by the National Academy of Sciences (NAS) Biological Effects of Atomic Radiation (BEAR) Genetics panel on a type of "meta-analysis" of five fruit-fly studies in which several of the studies (a) had significant study design and execution limitations, (b) were not published in peer-reviewed journals, and (c) the data from the two chronic experiments of Uphoff have not been found to verify the integrity of the research. [Episode 9];
7. Opposition to above-ground nuclear weapons testing was led by geneticists relying on the LNT model to challenge the Atomic Energy Commission statement that the fallout exposures were below a level of health concern. [Episode 10];
8. The influence of money on the creation of six NAS BEAR panels to assess environmental and health effects from radiation in which one panel, Genetics, had agreed that the LNT model was indisputable before initiating any debate. The Chair also identified the group (including himself) as "conspirators" that will receive "a very substantial amount of free support for genetics if at the end of this thing we have a real case for it." [Episodes 11 and 15];
9. The NAS BEAR Genetics panel chose not to assess the only 10-y epidemiologic study of Japanese atomic bomb survivors (75,000 subjects) that had not shown effects as part of their deliberation, despite their agreement that human studies were of greatest interest. Instead, the NAS BEAR Genetics panel report based its conclusions on flawed fruit-fly studies. [Episode 11];
10. The NAS permitted the arbitrary modification of nine Genetics panel members' estimates of generational mutations resulting from a hypothetical dose of 0.1 Gy to 160 million children. The committee fabricated the scientific record by arbitrarily excluding three of the lowest estimates and publishing that only six estimates were provided. It's also worth noting that three other panel members refused to provide estimates. Therefore, of the twelve member Genetics Panel, three refused to participate, nine provided estimates, and three were excluded. The reason for the exclusion was to reduce the uncertainty among those who did provide estimates to enhance public acceptance of their findings. The committee then falsified

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the scientific record when they chose to report a lower overall uncertainty than that calculated by the six remaining estimates. Despite inquiries to justify these decisions, the NAS President at the time decided that the panel did not need to provide a justification, leaving the public record to reflect an arbitrarily low uncertainty while artificially enhancing the consistency among the panel members and giving their message enhanced credibility. [Episodes 12 and 14];

11. How the NAS BEAR Genetics panel report set the foundation for radiation protection guidance, policies, and regulation to accept and incorporate the LNT model vs. a threshold model for cancer risk assessment. [Episode 13];
12. How cancer, specifically leukemia, became the focus based on a key study by Edward B. Lewis, a Nobel laureate, who misinterpreted other studies claiming they supported the LNT model, when the original researchers stated that their work should not be used to assess effects from low-level exposures. [Episode 16];
13. Thirty years of several follow-up studies of the Japanese atomic bomb survivor data showing a J-shaped dose response (e.g., hormesis, adaptive response). [Episode 17];
14. How the precautionary principle replaced the single-hit theory. [Episode 18];
15. That genetic repair was discovered in 1958 and accepted by the NAS BEAR II Genetics panel. The female mice showed a threshold for damage at 27,000 times background as described by Russell[1]; the males showed strong repair as well but failed to show a threshold, leading to the continuation of LNT by the BEIR I Committee. [Episode 19]. This conclusion was shown to be in error in Episode 21 (see # 17);
16. That reliance on flawed mice studies served as the scientific basis for continuing the LNT model for cancer risk assessment [Episode 20]; and
17. The discovery of a fundamental scientific flaw in mice studies resulted in an ethical investigation by the US Department of Energy (US DOE). This discovery required the Oak Ridge researchers (Bill and Liane Russell) to correct the record. That scientific change now supports a hormetic response in female mice and a threshold response in male mice. [Episode 21]. Had these new findings been known when the BEIR I committee was developing their recommendations, greater consideration may have been given to a threshold model.

[1]Russell WL. Summary of the effect of dose rate on the induction of mutations by radiation in the mouse. In: Environmental effects of producing electric power: Joint Committee on Atomic Energy. 91st Congress of the United States: Part 1, Appx. 11; 1969.

I must assume that Bahadori was aware of all these scientific failings and decided they were irrelevant, since he fails to mention them as new scientific data or information. I believe many in our field were not aware of these scientific issues that ultimately led to the replacement of the threshold model with the LNT model. To understand a science, one must know its history. The history of the LNT model is replete with errors, scientific misconduct (see #10 above), and represents a failing of scientific integrity at multiple levels (e.g., BEAR genetics panel, Science journal, and the US NAS). The few references provided by Bahadori do not refute or dismiss the facts presented in this documentary. Additionally, none of the documents presented in the documentary have been disputed. I encourage everyone to consider Bahadori's references, and I suggest adding the recent NCRP Commentary 27 to his list that support the LNT model (NCRP 2018). Readers should also be aware that a draft version of Commentary 27 was critically reviewed by Ulsh under the auspices of the American Academy of Health Physicists (Ulsh 2018). In his review, he provided 117 comments to NCRP, of which 108 were apparently disregarded. There are thousands of other references that counter the pro-LNT references provided by Bahadori. My response is not to engage in a retaliatory exchange of pro vs. con sources supporting the topic; it is to educate our field of its history.

Regarding the supporting documentation promised in the videos, it is unfortunate that my HPS Presidential discretionary funds were limited by the HPS Board of Directors and have effectively precluded any such constructive efforts. The 10,000+ documents in Calabrese's library were obtained using his personal funds from many private libraries and archives, each with their own legal features, including ownership and copyright issues and access, fee, and timing issues. Efforts are needed to examine the supporting documentation in more detail to determine specifically which items are most important and relevant to supporting the video series. This will require substantial resources and negotiations with the various institutions with ownership or copyrights. This will take a strong commitment by the HPS Board and President but could result in a treasured resource on scientific history for future researchers. At this time, the alternative is for interested persons to seek the referenced materials from their sources individually. All the source documents used in the video documentary have been clearly referenced in several of Calabrese's peer-reviewed publications, which are also listed at the end of each episode (Calabrese 2009, 2011a, 2011b, 2011c, 2012, 2013a, 2013b, 2014a, 2014b, 2015a, 2015b, 2015c, 2016, 2018a,

[1]Letter from John Cardarelli to Roger Coates, IRPA Past-President, 8 May 2022. Available at https://hps.org/govtrelations/documents/Cardarelli_response_to_Coates.pdf.

2018b, 2019a, 2019b, 2019c, 2020, 2021a, 2021b, 2021c; Calabrese and Giordano 2022).

I respectfully disagree with Bahadori's suggestion that (1) these videos take a position on any cancer risk dose response model and (2) the historical events allegedly occurred. First, this documentary presents historical facts on how the LNT model ultimately replaced the threshold model and where studies failed to assess the potential for threshold or hormetic responses (e.g., atomic bomb survivors). The history reveals a series of miscues by scientists and organizations, whether they were intentional or not, and admittedly does not reflect well on those who choose to ignore the past while currently promoting the LNT model for cancer risk assessment in low-dose environments. That does not equate to being an "anti-LNT" documentary, as Bahadori suggests; dismissing the past, in some respect, is anti-science. Using more recent and select studies that show support for the LNT model does not erase the troubling history, especially when other recent studies continue to contradict those supporting LNT.

Second, the facts are clear—the events didn't "allegedly" occur; they did occur. Supporting documents are cited, and this is the history of our field of radiation protection. We must acknowledge and own it. This history reflects the path taken by scientific organizations and regulatory agencies to justify the use of the LNT model for radiation protection purposes under questionable motives and scientific beliefs. Bahadori's appeal to authority by referencing the US NRC 2018 review oversimplifies and overstates their position to support his argument. Politics have a role in policy that cannot be ignored, but science is based on objective facts, and it is clear that the history of how the LNT model came to be was based on flawed scientific methods, political pressure, and in a few specific instances, documented misconduct at the highest levels. Given this history, should we continue to rely on the LNT model in times of crisis? That's a question to be addressed in another commentary.

Finally, Bahadori's attempt to dismiss these historical facts discovered by Calabrese as not particularly germane to current radiation practices is similar to a comment I received from IRPA Past President Roger Coates. I encourage readers to see my response to his comments.[1] Furthermore, Bahadori's characterization of the videos as being a series of unsubstantiated, unchallenged allegations is simply inaccurate. He provides no documentation to dispute the source documents cited in the videos supporting his statement. In my opinion, it remains in the best interest of the profession for the Health Physics Society to promote these videos, create more videos, continue to pursue the truth in science, seek additional information, and encourage civil debate on the health effects associated with low-dose exposures to radiation. In this context, I welcome Bahadori's review and wish to point out that Episode 22 presents alternatives that are more scientifically robust and suggests a path forward.

Now, I would like to comment on Bahadori's response to Gale and Hoffman regarding the ANS position statement. Here, we are in total agreement. I would also like to point out that HPS and many other scientific organizations have position statements similar to the American Nuclear Society (AAPM 2018; SRP 2001; UNSCEAR 2012). They generally caution against the use of estimating risks at or near background doses due to biological and epidemiological uncertainties. Even the US Environmental Protection Agency's Science Advisory Board recommended the agency consider new paradigms associated with biological response to low doses of radiation (Cardarelli and Ulsh 2018).

The issue with the LNT model appears to be how it is implemented inconsistently around the world. For example, the US EPA literally applies a risk-based approach based on the LNT model to determine cleanup levels for contaminated environments. As a result, EPA policy states that any exposure above 0.12 mSv y^{-1} is not protective. US EPA derived this value by using the LNT model and dividing 3×10^{-4} excess cancers by a risk of 8×10^{-7} cancers per mrem (375 mrem or 3.75 mSv). This value is then divided by a 30-y lifetime exposure, resulting in an estimated dose of 12.5 mrem y^{-1} (0.12 mSv y^{-1}). This is the upper limit of acceptable risk typically applied by the US EPA. The default risk value is 1 in a million (0.0001%) excess cancers, which would result in an annual dose of 0.0004 mSv y^{-1}. The literal application of the LNT model clearly results in overly conservative cleanup values and introduces a host of political, economic, and social issues that are not consistent with the scientific guidance as described in the various position statements.

Even the international community agrees that estimating risks at these levels is inappropriate. Perhaps that may be why the international community continues to endorse the LNT model for radiation protection purposes—because other countries do not literally apply it to determine environmental cleanup levels. There are many examples that can illustrate this, but I'll only mention one. The Po-210 cleanup levels following the murder of Alexander Litvinenko in London were based on a 1 mSv annual dose, roughly equivalent to 10 Bq cm^{-2} (fixed contamination). This is a dose-based criteria that was not derived from the LNT model. It essentially represents a threshold model. The authorities stated, *"Levels of contamination below this*

[2]United Kingdom, Health Protection Agency: Monitoring Program for Polonium-210 carried out by HPA in premises and other sites relevant to public health. Available at https://webarchive.nationalarchives.gov.uk/ukgwa/20140714084352/http://www.hpa.org.uk/webc/HPAwebFile/HPAwebC/1194947411630. Accessed on 21 December 2022.

[2]Low-dose region in this context is arbitrarily defined as less than 100 mSv cumulative dose and less than 1 mSv y^{-1}.

value do not need remediation on health grounds, although it is good practice to remove contamination where this is easily achievable." In contrast, the US EPA cleanup policy, based on the LNT model with an acceptable excess cancer risk of 1 in a million, results in a Po-210 cleanup value of 0.000011 Bq cm^{-2} (surface preliminary remediation goal for settled dust). There is at least a 900,000-fold difference between the UK and US cleanup numbers, and the only reason for it is due to a US policy that literally applies the LNT model and uses it in a manner that is inappropriate and recognized as such by the international radiation protection community.

The ICRP recommends a band of 1 mSv to 20 mSv y^{-1} for existing exposures, taking into account the actual distribution of doses in the population and the societal, environmental, and economic factors influencing the exposure situation (Kai et al. 2020). These values were not derived by using the LNT model. If the international community were to expand the statement, "The LNT model is used for radiation protection purposes" to include a key qualifier like "The LNT model is used for radiation purposes *down to an acceptable dose of 1 mSv* y^{-1}," it would help to harmonize the application of the LNT model for radiation protection purposes. It would also bring clarity, simplicity, and consistency for environmental cleanup decisions, emergency response decisions, constructing less expensive nuclear power plants, improve risk communication for people fearful of medical imaging risks, and educate the population on where the measurable risks to radiation exposure reside. A statement like this should prevent the literal application of LNT to levels where the uncertainties are too great to have any scientific validity. I believe this is a reasonable approach toward harmonizing radiation protection policies in the low-dose region[2] while accommodating those who believe the LNT model has merit in the low-dose region.

JOHN CARDARELLI II
Health Physics Society Cincinnati OH

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