Review of the RHIC Safety Review

Introduction

The question is whether Brookhaven's RHIC might destroy the world by creating strange matter in energetic gold on gold collisions. This safety issue is extraordinary and unprecedented due to the scale of the concern. A wrong decision could lead to a disaster of nearly unimaginable proportion. The recently revised "Review of Speculative 'Disaster Scenarios' at RHIC" [4] (May 2000, hereafter called the "Review") concludes that a disaster scenario is "extremely unlikely" and that strangelets are "impossibly difficult to produce at RHIC."

In my Web page, "The Strange Matter of Planetary Destruction," [5] I computed an acceptable maximal probability, $\mathbf{p}$, for disaster at the RHIC of 10^{-18} based on a rudimentary calculation using a billion years as the anticipated useful life of Earth. On further reflection that figure is far too liberal. If this safety issue were to occur a couple of hundred years in the future, and if it could be safely assumed that human habitation in space or on other planets would become routine by then, then that billion-year accumulated worth for the planet Earth would be appropriate. As it is now, with all of humanity living on Earth and unable to survive in space, the value of Earth must be considered to be infinite, as that is the worth of all of humanity, and it is all of humanity that would be destroyed as a result of a strangelet accident at the RHIC. In these circumstances, extraordinary caution is called for in performing a safety analysis. As I show here, the knowledge available to date indicates that the computed probability of disaster at RHIC does not even meet my earlier, more liberal, safety criterion ($\mathbf{p} < 10^{-18}$).

To support my conclusion of danger, I show that the credibility of the Review is severely compromised by several errors and contradictions it contains. The Review supports its own conclusion of safety by a set of assertions, any one of which being true assures the safety of the RHIC. These assertions include the following:

1. Large strangelets will be unstable (unable to exist for any significant period of time) at low pressure.

2. Intermediate size strangelets will be unstable (not metastable).

3. There must be a continuous line (in the mass-charge space) of stability for negative strangelets (assuming positive strangelets are benign) for them to be dangerous (and it is sufficiently unlikely that such a line of stability should exist).

4. Intermediate size strangelets are not producible in the RHIC collision environment.

Not one of these four assertions was proven conclusively (let alone with a certainty of $1 - 10^{-18}$, which is the desired minimal probability of no disaster) in the Review and further, assertion 3, above, depends on the assumptions that neutral strangelets cannot stably exist and that positive strangelets are completely benign, neither of which has been proven in the Review.

The Review authors set forth theoretical arguments purporting to prove the four assertions above (with certainty $> 1 - 10^{-18}$) In addition, they use the evidence of billions of years of lunar cosmic ray exposure to argue against dangerous strangelet production, yet they contradict that very conclusion in their admission that the "Moon does not provide useful limits [on the probability of destruction] for targets less abundant than iron" (page 23, meaning gold atoms with nearly four times the mass of iron atoms, as will be used in the RHIC).

Proper safety analysis requires that worst case scenarios be addressed, because it is in just these worst cases that accidents occur. For example, the space shuttle Challenger disaster occurred because engineers in charge overlooked the effects of a worst case cold launch temperature on the solid motor O-ring seals. Good engineers routinely design for worst cases. In view of the high cost of a strangelet disaster (total destruction of the Earth and all its life), it is inappropriate to consciously overlook any worst case in computing a probability of disaster.

The Review authors claim that an upper bound on probability, $\mathbf{p}$, of a single dangerous event in the lifetime of the RHIC, is estimated, that excludes a dangerous event beyond "any reasonable level of concern" (page 3). However the calculations performed indicate values for $\mathbf{p}$ of 10^{-11} (page 24) or 10^{-12} (page 18[1]), a result several orders of magnitude higher than a maximal acceptable (10^{-18} [5]) probability. To fully counter the Review's conclusion of safety, I undermine all four of the assertions, above, as follows:

Assertion 1

> Large strangelets will be unstable (unable to exist for any significant period of time) at low pressure.

Assertion 1 is addressed on page 13 of the Review: "To obtain stable strange matter it is necessary to reduce the value of the bag constant below traditionally favored values. This is the reason we describe stability at zero external pressure as 'unlikely'." A scientific preconception is called a hypothesis. In the scientific method, a hypothesis is tested, and either rejected or accepted as a foundation for further hypotheses. The history of science is literally a story of rejected hypotheses, with some surviving to become valid theory. Many scientific traditions have survived for a time and later been supplanted by superior

[1] The probability computed on page 18 is 2×10^{-35} for an example strangelet of $A = 20$, $Z = -1$, and $S = 22$. However, assuming that the probability is an inverse exponential function of strangelet mass, the probability for a strangelet half that size works out to 10^{-12}.

theory. While the authors of the Review believe it is unlikely in this case, it is difficult to assign a probability of their correctness at this time, hence a probability < 10^{-18} has not been shown.

Assertion 2

> Intermediate size strangelets will be unstable (not metastable).

Finite size effects in strange matter are discussed on page 14 of the Review. The surface energy of strange matter will tend to destabilize intermediate size (A > 30) strangelets. However, some researchers believe that intermediate size strangelets will indeed be metastable and have even proposed holding them in an electromagnetic trap and feeding them neutrons to grow them to stable size. It has been proposed that such a system could serve as a power source [3]. Joshua Holden concludes in his "Story of Strangelets" [3]:

> It is not clear that strangelets exist naturally, can be produced, or are stable enough to be detected. Searches have so far found no evidence of them. But while it is not clear that they must exist, they cannot be ruled out. The allowed range of parameters for stability is fairly wide, and the values are not unreasonable. The arguments that motivated the first discussions of strange matter remain valid reasons to expect it.

Thus, theoretical opinion on the metastability of intermediate size strangelets is divided and assertion 2 has not been established.

Assertion 3

> There must be a continuous line (in the mass-charge space) of stability for negative strangelets (assuming positive strangelets are benign) for them to be dangerous (and it is sufficiently unlikely that such a line of stability should exist).

Assertion three is undermined in two ways, either of which is sufficient alone to invalidate it. First, I show that there is a significant probability (>10^{-18}) that a continuous line of stability exists, and second, that the Review authors' assumption that non-negative strangelets are necessarily harmless is incorrect.

The first undermining of assertion 3 is assisted by the Review authors themselves, where they state on page 16:

> Even though these features of strangelet stability could stop the growth of a negatively charged strangelet produced at RHIC, we cannot use them to argue for the safety of the RHIC because we do not know how to model them accurately.

The second undermining of assertion 3 is in two parts:

a. If a neutral strangelet should be produced, it would have no Coulomb barrier to spontaneous and greedy exothermic fusion with hadronic matter, and thus would be extremely dangerous. Neutral strangelets are not addressed anywhere in the review.

b. A positive strangelet will become dangerous when it grows to a size in which the strangelet radius exceeds the Bohr radius at a size of $A \approx 10^7$. Thus, capturing a positive strangelet in an electrostatic trap and feeding it neutrons (as proposed by some researchers [3]) would be exceedingly dangerous. The Review authors obviously overlooked this when they assert that "positively charged strangelets pose no threat whatsoever." (page 4)

Assertion 4

> Intermediate size strangelets are not producible in the RHIC collision environment

The Review authors attempt to establish assertion 4 by refuting two possible mechanisms for strangelet production in an energetic heavy ion collision: strangelet distillation, and strangelet coalescence (and a related thermal model of production).

The coalescence example on page 18 of the Review (A = 20, Z = -1, S = 22), was chosen to provide a very small probability per collision of 10^{-46}. Using a strangelet of half that mass results in a much larger computed probability of 10^{-23}, which over the lifetime of the RHIC gives a probability of 10^{-12}, several orders of magnitude greater that the desired safety limit of 10^{-18}.

The strangelet distillation model is called "more speculative" in the Review (page 19), but it is cited by other researchers [2]. "This mechanism preferentially produces negatively-charged strangelets." [1] Because strange quarks are more massive than up or down quarks, thermal energy will tend to flee the central region of the quark-gluon plasma (QGP) as baryon kinetic energy leaving an excess of strangeness in the coalescing central region. Gamma photon cooling is another process that may influence strangelet formation.

Cosmic Ray Arguments

The authors of the Review state on pages 2 and 3:

> What is truly novel about heavy ion colliders compared to other accelerator environments is the volume over which high energy densities can be achieved and the number of quarks involved.

Cosmic ray collisions with lunar iron nuclei do not replicate conditions in the RHIC as the authors of the Review acknowledge when they write on pages 24 and 25:

> If however, one insists on recreating exactly the circumstances at RHIC and insists on the worst case rapidity distribution, then lunar limits are not applicable.

Thus, the Review authors seem to initiate a contradiction when they write on page 21:

> It is clear that cosmic rays have been carrying out RHIC-like "experiments" throughout the Universe since time out of mind.

The main point of a safety inquiry is that the RHIC will create unprecedented energy density and volume together. This condition has not occurred naturally since the big bang when the quark-gluon plasma condensed into mostly protons and neutrons. If any strangelets were formed at that time, they may still be evident as the accreted cores of galaxies.

Conclusion

The RHIC is to be considered dangerous if the total probability (over its lifetime of operations) of destroying the world should exceed 10^{-18}. This is not an arbitrarily small number, but has been arrived at using standard risk management methodology and some reasonable assumptions about the value of our home world [5]. The safety of the RHIC is ostensibly established in the Review by the four assertions above, any one of which, if true, is sufficient. I have shown that all four of the assertions are significantly undermined such that the 10^{-18} probability criterion cannot be established, effectively refuting the Review. The authors of the Review, knowing that theoretical arguments for safety alone are weak, call upon cosmic ray arguments which I have also shown to be suspect.

References

[1] Nikos Drakos, E864 Experiment Proposal, DOE, Web published, http://helena.phy.vanderbilt.edu//e864/physics/doe_proposal_root/

[2] C. Greiner and H. Stöcker, Phys. Rev. D (in press).

[3] Holden, Joshua, “The Story of Strangelets,” Web published, http://www.physics.rutgers.edu/~jholden/strange/strange.html, May 17, 1998.

[4] R. L. Jaffe, W. Busza, J. Sandweiss, and F. Wilczek, “Review of Speculative ‘Disaster Scenarios’ at RHIC,” May 19, 2000, unpublished as of this writing.

[5] Richard J. Wagner, “The Strange Matter of Planetary Destruction,” Web published, http://chess.captain.at/strangelets-matter.html, May 17, 2000.