

# The Policy Effects of the Radiation on Mars

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## Abstract

Were humans to build a colony on Mars it would be important to understand the nature of radiation on the Martian surface and the effects it would have on the colonists. Once the designers of the colony understand all of these effects, they will realize that it is of paramount importance to protect the colonists from the mutagenic affects of Martian radiation. This paper first examines the amount and nature of the radiation on the surface of Mars and then the conflicting theories as to the detriments or benefits the mutations arising from this radiation would confer upon the colonists. The resolution of these theories leads to the conclusion that Martian colony designers should take measures to avoid both the positive and the negative effects on colonists of mutations induced by radiation exposure. The remainder of the paper deals with the potential ramifications for the failure to reduce exposure to radiation and the damage it causes to genetic material and then presents novel solutions to do so.

In the near future it is probable that the United States, either alone or in conjunction with other nations, will send humans to the planet Mars. Judging from previous exploratory voyages, both terrestrial and extra-terrestrial, following this historic voyage at some point there will be a call to colonize the planet. Exercising caution is imperative in undertaking such a program for there are numerous risks involved, some of which would affect the health of the colonizers. There are also certain risks to the crew, such as radiation, the effects of which would have wider implications on humanity as a whole because of the specific effects it would have on the members of a colony. A human settlement on Mars would expose humans to types of radiation and radiation levels that are quite different from those found on Earth, steps should be taken to reduce this exposure because of the profound biological and cultural effects that such exposure would have.

An individual on Mars would receive approximately 272 millisieverts of radiation per year, mostly in the form of ultraviolet radiation (<http://seds.lpl.arizona.edu/pub/info/mars/RadHuman.txt>; <http://spot.colorado.edu/~marscase/cfm/articles/biorev3.html>). A comparison to a man on Earth and his radiation dose of 3.6 millisieverts in one year shows this dosage to be quite substantial (Letaw, 2001, 339). The Earth possesses protective barriers that account for the difference in radiation levels between our planet and Mars, and while some of them shield the Earth from one type of radiation, others are responsible for obstructing several different kinds. The most familiar protection that the surface of Earth has against organically harmful radiation is the ozone layer. This atmospheric stratum

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There is a difference between the amount of radiation to which an individual exposes himself, and the amount that he absorbs (the difference between roentgens and rads/sieverts). However, "since the energy deposited in soft tissue by 1r is only 5% greater than 1 rad" exposure and absorption will be considered synonymous for the purposes of this paper (Christensen et. al., 1978, 397).

consists of ozone, O<sub>3</sub>, which absorbs electromagnetic photons in the ultraviolet range effectively providing a screen against them for the organisms on the surface.

Additionally Earth has a magnetosphere that is the product of the spinning of the liquid portion of the core of the planet. The movement of the Iron-Nickel core acts like a dynamo, establishing a magnetic field around the planet as though it were bisected by a bar magnet (Thorstensen, 2001). Because the magnetosphere is a giant magnetic field it greatly influences charged particles produced by the sun, known as the solar wind, that are moving through space, deflecting them away from the Earth ([http://science.nasa.gov/headlines/y2001/ast01may\\_1.htm](http://science.nasa.gov/headlines/y2001/ast01may_1.htm)). Mars lacks both of these strata and as a result a human on its surface would be subject to a much more brutal dose of ultraviolet radiation and solar wind, although the planet's atmosphere does protect it somewhat from the solar wind ([http://science.nasa.gov/headlines/y2001/ast01may\\_1.htm](http://science.nasa.gov/headlines/y2001/ast01may_1.htm); <http://science.nasa.gov/headlines/y2001/ast31jan%5f1.htm>). The third type of radiation is known as Galactic Cosmic Radiation and is comprised of atoms of Iron and lighter that have been stripped of their electrons and are moving at very high velocities. These cations are the products of supernova explosions and permeate space. Obviously because of their charge the magnetosphere affects them as well, but so does the planet itself. Thus, on Mars where there is no magnetosphere the physical mass of the planet itself blocks these particles, since they come from all three dimensions, albeit not as well as a larger planet would (Buckey 2001).

The effect that radiation has on the body depends on the type of radiation being discussed, but in general most kinds of radiation are deleterious because of the effect that they have on DNA. Ionizing radiation, such as Galactic Cosmic Radiation and solar

wind, can cause free hydroxyl radicals, single, and double stranded breaks in DNA, which can normally be repaired, however it can also cause much larger problems (Jack, 2000). Ionizing radiation can also cause large chromosomal deletions where several genes can be lost. This form of radiation is also responsible for single gene mutations as well as multi-allele mutations in a single cell. In fact these particularly dangerous multi-allele mutations are actually found most frequently (Evans, 1990, 216).

Ultraviolet radiation is a form of electromagnetic radiation and as such it has no particles of mass associated with it. Consequently, it does not contain enough energy to act as a form of ionizing radiation which, as the name indicates, has enough energy to remove electrons from (Letaw, 2001, 336). Rather, ultraviolet radiation causes two adjacent thymine residues in DNA to dimerize, connecting themselves with a cyclobutane ring. The dimers then preclude the normal transcription of the gene because they act in a manner analogous to a roadblock, preventing the “reading” of the gene downstream from them (Jack, 2000). The inability of the cellular mechanisms to read through these blockages renders the gene incomprehensible and prevents the production of the product that it codes for, thereby causing a loss of function mutation.

The fact that ionizing and non-ionizing radiation produce mutations in living organisms is important, but there are two different interpretations of the nature of this importance, and two and two different theories that correspond to these interpretations. Known as Balance and Classical Theories, they contain divergent conclusions regarding the general effects that mutations have on an individual’s health. The first of these theories, Balance Theory, regards mutation as beneficial because it adds to genetic diversity. However, Classical Theory, or Classicism, argues that mutations are generally

individually detrimental, and therefore taken as a whole are harmful to organisms. A closer look at the arguments and evidence presented provides the basis for a determination as to which theory is correct.

The main proponent of Balance Theory was Theodosius Dobzhansky, a Zoology professor at Columbia who took an active interest in genetics and the role that it played in evolution. In general he regarded homozygosity as an evolutionary detriment because it restricts the diversity of a species and because there are genes that are more beneficial when heterozygous than when homozygous. "...Genes may be maintained in human populations in balanced states either because of being advantageous in heterozygotes or because of the action of diversifying selection (Dobzhansky, 1962, 298)." Thus, heterozygotic individuals are the most hardy members of a population because not only do they carry a great deal of genetic diversity, which allows them to respond better to changes in selection pressures, but also the nature of their heterozygote gene combinations produces advantageous biochemical products.

Dobzhansky's argument that heterozygosity is evolutionarily beneficial is supported by the observation that heterozygosity provides more genes, because of the differing alleles, for that individual to draw upon. Therefore, he concludes that such an individual would fare better when put under environmental stresses (Dobzhansky, 1962, 296; Dobzhansky, 1970, 136). Wallace's findings in his radiation experiments support this conclusion. Wallace took two groups of *Drosophila* flies and irradiated one with X-rays, measuring their "relative viabilities" and that of their offspring for several generations. He concluded that those that had been irradiated, and therefore had more mutations and a greater heterozygous character, were hardier than those that were not

exposed to radiation (Wallace 1958, 542, 555-556; Wallace 1951 220-221; Wallace, 1956, 290). The support offered for the second portion of Dobzhansky's argument, the benefits of overdominance, is an analysis of sickle-cell anemia. Here Dobzhansky aptly notes that individuals who are heterozygous for this trait are resistant to malaria, while those who are homozygous for the "normal" allele suffer its full effects (Dobzhansky, 1962, 297; Dobzhansky, 1964, 133).

H. J. Muller strongly advanced the contrary theory, known as Classicism. Muller was one of the founding members of the discipline of modern genetics and in this role he worked often with *Drosophila*. His experiments specifically dealt with the effects of X-rays on the flies, which he noted often induced mutations (Muller 1928, 245). It was his study of the type of mutations that generally arose and the consequences that an accumulation of these mutations would have that led him to conclude that mutations in general were deleterious and an accumulation of them even more so.

Muller's work produced many mutations, which he noted were proportional to their exposure to radiation (Muller, 1955, 586). He took the time patiently to categorize all of the mutations, the results of which were not disturbing for Muller in and of themselves, but they became so when he generalized them to humans. Muller noted that the great majority of the mutations he observed were detrimental and often lethal to the organism, while almost all were recessive (Muller, 1950-1, 568; Muller, 1955, 585; Carlson, 1981, 124). What gave Muller cause for greater concern was later findings that recessive genes were almost never completely recessive but were normally expressed in some extremely small amount (Muller, 1950-1, 570). Again, extrapolating to humans Muller became worried because when the two findings were combined he noted that an

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The phenomenon of greater vitality due to a specific heterozygous allele is known as overdominance.

individual would collect recessive mutations that would not be overtly expressed, but would, increment by increment, slowly reduce his health as he accumulated them (Muller 1950-2, 342). When this conclusion was paired with the fact that the pressures of natural selection had been ameliorated by human advances in medicine, he saw the possibility for the steady accumulation of negative, but recessive, mutations in the human gene pool that would slowly erode the health of man (Muller, 1950-2, 342).

Reaching an experimental resolution between these theories is not easy, primarily because they both deal with the effects that mutations would have on the evolution of a species, which is a process that takes a great deal of time. However, a critical examination of the evidence that supports them, as well as some subsequent experimental evidence, can help us to draw a conclusion as to the ultimate consequences of mutation. The occurrence of a beneficial form of overdominance is exceedingly rare. The typical example, and indeed the one used by Dobzhansky, is that of sickle-cell anemia, but there are no others mentioned in his work or the work of the other evolutionists consulted (Dobzhansky, 1962; Dobzhansky, 1964; Dobzhansky, 1970, Nielson, 1995; Shull, 1948).

That is not to say that Balance Theory is without its merit, for as it notes, mutation is an imperative for evolution because without it life would probably have remained in the form of unicellular obligate anaerobes. Similarly, the conclusions of Classicism have merits and weaknesses. While it does correctly note that without selective pressure mutations will accumulate in organisms, it vastly overstates the deleterious effects of mutation (Muller, 1950-2, 342). The analysis of DNA sequence data, pioneered by Motoo Kimura, has shown that the mutational frequency of genes does not correspond with the mutational frequency of the gene products. That led him to propose that most of

the mutations DNA suffers are neither harmful nor beneficial, but rather neutral (Kimura, 1962). The degeneracy of the genetic code speaks to the validity of this claim as there are at least two or more coding sequences for all the amino acids except two. Thus, a mutation need not necessarily result in a change in the protein. Additionally, advances in molecular biology have resulted in the conclusion that mutations must occur at specific vital locations for them to affect gene function (Jack, 2000). Therefore mutations will occur and accumulate in humans as the result of radiation, but the accumulation will have neither the disastrous effects predicted by Muller's Classicism nor the benefits predicted by Dobzhansky's Balance Theory.

This end result has implications for the colonizers of Mars; mutations that arise will on occasion be deleterious, but they will also add to the genetic diversity of the group. This diversity is important because the selective pressures that will be applied on Mars will be different than those found on Earth, so it will allow for a greater opportunity to biologically adapt to the new planet. However, the ultimate results of these mutations may not be as beneficial as they appear to be, as it is probable that they will cause the rise of a negative eugenic program and create conditions that will lead to the permanent segregation of these colonists from the portion of the human species remaining on Earth.

Negative eugenics is the process of preventing transmission of genetic material responsible for undesired traits from being transferred from one generation to the next (Dietrich, 2001). The most common example of such a practice was the sterilization of persons committed to sanatoriums to prevent them from procreating and passing the genes that caused their mental illness along to another generation. The production of deleterious mutations among colonists would be increased compared to those remaining

on Earth because of their increased exposure to radiation. These mutations warrant concern because a colonial culture out of necessity may be less tolerant of the expression of such mutations. In a colonial setting there is a high premium on productivity and individuals who have mutations that prevent them from being as productive as other members of the colony are a drain on the group's resources. Because of this negative affect on the community, the colonists will probably apply negative eugenics to ensure that such individuals are not produced. This use of eugenics, while necessary from the standpoint of the colonists, invites abuse, since the definition of what is "unacceptable" may balloon and create a situation analogous to Nazi Germany. People can apply in a limited fashion but the degree of state control over the process in a Martian colony makes me skeptical that this situation is one of those cases.

The permanent segregation of the settlers from the rest of the human species will, like a eugenics program, arise out of necessity. As mentioned earlier, mutations need not be detrimental to an organism, rather they can be positive. Since Mars would apply different selective pressures on humans than a terrestrial environment, different traits would become desirable. Some of these desirable traits will arise as a result of the increased mutations that the radiation on Mars will produce and will begin to permeate the colony as it is a small, inbreeding group. While adaptation is typically thought of as a slow process involving many genes, there is evidence that saltational changes in genomic structure are involved in adaptation to an environment, albeit somewhat rarely (Fisher,

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Germany's eugenics program was initially based on California's eugenic program. However, the high degree of state control in Germany versus that in the United States is what led to their differing evolutions. The state control, as it were, in a colony would probably be more analogous to the pre-WWII German political situation than that of the United States in the 1920's and 1930's since the doctors involved will probably not be independent professionals practicing medicine, but rather working under the auspices of the colonial government. Thus, I am concerned.

1997, 113). While this adaptability is a good thing for those living on Mars, it also presents problems. Were people carrying new genes from an outside population, such as Earth, to arrive in this isolated inbreeding population a result known as Hybrid Vigor, or heterosis, would occur which would have disastrous results. Normally the offspring of the two groups is more vigorous than either of the parental groups because the deleterious mutations it received from one were suppressed by the healthy alleles it received from the other (Shull, 1948, 28-36; Dietrich, 2001; Strunnikov, 1995, 297-299). This premise is built on the reasoning that since it is unlikely that the inbreeding population on Mars will have the same collections of spontaneous deleterious mutations as the incoming group, from Earth, and one group's healthy genes compliment the other's mutant ones. The problem arises when a number of advantageous mutations have collected in a population. An influx of individuals who have the "normal" alleles of these genes will wipe out these mutations.

These two effects, the creation of deleterious mutations that colonists will need to eliminate and the creation of advantageous ones that will need to be preserved, have deeper consequences for a Mars colony. The practice of aborting fetuses because of a genetic defect, or manipulating the development of a fetus to achieve this same end, may be offensive to some colonists and become a source of tension. Additionally, such processes because of their nature are open to gross manipulation as their past history has shown. Thus, it would be desirable to eschew the need for such a program. Furthermore, from a cultural and biological standpoint, the colony will begin to develop differently than the cultures of humans on Earth. The inability to introduce additional colonists because of the disruption that it would cause in the propagation of advantageous genes

would biologically isolate the colony. Because of the inability of people from Earth to integrate into the colony and the inability of those living on Mars to return to the Earth because of their growing adaptation to their new planet, a cultural isolation will begin to develop. The combination of these two forms of isolation will create a dichotomy in the human species, and may ultimately result in its divergence. While some may argue that this direction is beneficial, and the diversification of the species will help us not only to evolve but also to grow in a more abstract way, I do not. The prevalence of conflict over the existing cultural and biological diversity among humans indicates that we may be not be ready to deal with further heterogeneity.

With these difficulties in mind it would be possible to establish a colony on Mars after taking certain precautions to reduce the radiation exposure of the colonists and thus the root cause of the problems examined above. Obviously the colony could utilize shielded materials for the construction of its habitat. For this purpose lighter materials, such as polyurethane work best because they absorb the charged particles that comprise the Galactic Cosmic Radiation and solar wind (<http://www.cnn.com/2000/TECH/space/09/08/mars.bars.ap/index.html>; Buckey, 2001). However, I would like to propose two unique solutions; the use of a bacterial protein and the strategic location of the colony (<http://science.nasa.gov/headlines/y2001/ast31jan%5F1.htm>)

All organisms have mechanisms that allow them to repair DNA damage and mutations, but there are many different types of these mechanisms and not all organisms have all of these different types. Notably there is one known as Enzymatic Photoreactivation Repair that is found in bacteria, but not mammals (Jack 2000). This repair mechanism consists of a single gene that produces a single protein. The gene is

activated by ultraviolet light and its product specifically repairs the damage caused by ultraviolet radiation (Jack, 2000). Such an enzyme would be phenomenally useful since, as Hiscox notes, “the main source of radiation at the Martian surface is ultraviolet (UV) radiation between the wavelengths of 190 and 300 nm” (<http://spot.colorado.edu/~marscase/cfm/articles/biorev3.html>). The enzyme could be injected in a manner similar to insulin; the gene itself could be introduced to the colonists or the first generation conceived on Mars, but to do so would serve to exacerbate the eugenics problem, not ameliorate it.

The other method of reducing the radiation a colony would receive would be to locate it in an area of Mars that retains a remnant of its magnetosphere. A network of magnetic loops have been found in the southern hemisphere of the planet that could serve as local “miniature magnetospheres” (<http://science.nasa.gov/headlines/y2001/ast31jan%5f1.htm>). Here one could establish colonies that would be as safe from the charged particles found in the solar wind and in Galactic Cosmic Radiation as an individual would be on Earth. This safety is the result of a “...magnetic field [is] about as strong as Earth’s – a few tenths of a gauss” (<http://science.nasa.gov/headlines/y2001/ast31jan%5f1.htm>). The placement of the colony in the area covered by these magnetic loops would free it from the need to either bring or synthesize the needed polyurethane for shielding from charge particles.

The establishment of a colony on Mars would indeed be an important moment for humans, yet there are problems inherent with such a plan. Colonists would develop genetic mutations because of the ionizing and non-ionizing radiation to which they would expose themselves. The mutations that would arise would result in both deleterious and advantageous phenotypic effects, with deleterious effects being somewhat more common. The manifestations of these effects would have broader implications for the colony in that

they may lead to the establishment and abuse of a negative eugenics program as well as the biological and cultural isolation of the colony from Earth. To guard against these outcomes I have suggested methods of reducing the effects of the radiation on the colonists DNA, and hence the number of mutations it would induce. The expansion of human boundaries, both spatial and intellectual, that such a colony would achieve would be enormous. However, it also has the potential to create a biological and cultural dichotomy within our species, one which currently has trouble surmounting those that already exist, and because of this potential, such a project should be approached cautiously.

## Works Cited

Associated Press. "Researchers Developing Bricks to Block Radiation on Mars."

CNN.com. 18 May, 2001.

<<http://www.cnn.com/2000/TECH/space/09/08.mars.bars.ap/index.html>>. from

<[www.cnn.com](http://www.cnn.com)>.

Buckey, Jay, Jr. "Radiation in Deep Space: Cell Death and Cancer." Rockefeller 1,

Dartmouth College. 5 May, 2001

Carlson, Elof Axel. Genes, Radiation, and Society: The Life and Work of H.J. Muller.

Ithaca: Cornell University Press, 1981.

Chappell, David T. "Radiation and the Human Mars Mission." The Stanford International

Mars Mission (SIMM) Study. 18 May, 2001.

<<http://seds.lpl.arizona.edu/pub/info/mars/RadHuman.txt>>. from <[www.arizona.edu](http://www.arizona.edu)>.

Christensen, Edward E., Thomas S. Curry III, and Jason E. Dowdey. Introduction to the

Physiology of Diagnostic Radiology. 2<sup>nd</sup> ed. Philadelphia: Lea & Febiger, 1978.

Dietrich, Michael R. "Eugenics and Social Reform." Moore B03, Dartmouth College. 24

May, 2001.

Dobzhansky, Theodosius. Genetics of the Evolutionary Process. New York: Columbia

University Press, 1970.

- - -. Heredity and the Nature of Man. New York: Harcourt, Brace,

and World, Inc., 1964.

- - -. Mankind Evolving, New Haven: Yale University Press, 1962.

Evans, Helen. "Ionizing Radiation Mutagenesis in Mammalian Cells, 1990." UCLA

Symposia on Molecular and Cellular Biology New Series, Volume 136: Ionizing

- Radiation Damage to DNA: Molecular Aspects. ed. Susan S. Wallace and Robert B. Painter. New York: John Wiley and Sons, Inc., 1990.
- Fisher, R. A. "The Genetical Theory of Natural Selection." Evolution. ed. Mark Ridley. New York: Oxford University Press, 1997. 112-115.
- Hiscox, Julian A. "Biology and the Planetary Engineering of Mars." Department of Microbiology University of Alabama at Birmingham. 18 May, 2001.  
<<http://spot.colorado.edu/~marscase/cfm/articles/biorev3.html>>. from <[www.colorado.edu](http://www.colorado.edu)>.
- Jack, Thomas. "DNA Mutagenesis and Repair." Filene, Dartmouth College. 3 August, 2000.
- Kimura, Motoo, Evolutionary Rate at the Molecular Level, *Nature*, 217, 624-6, 1968.
- Letaw, John R. "Radiation Biology." Human Biology 1, Earth Sciences 8: Life on Mars?, Volume 1. ed. Jay Buckey, Laurence Davies, and Mukul Sharma. Hanover: Dartmouth College, 2001.
- Muller, H. J. "Our Load of Mutations, 1950" Evolution. ed. Mark Ridley. New York: Oxford University Press, 1997. 341-346.
- - -. "Comments on the Genetic Effects of Radiation on Human Populations, 1955." Studies in Genetics. ed. H. J. Muller. Bloomington: Indiana University Press, 1962. 585-586.
- - -. "Our Load of Mutations, 1950" Studies in Genetics. ed. H. J. Muller. Bloomington: Indiana University Press, 1962. 560-572.
- - -. "The Artificial Transmutation of a Gene, 1928." Studies in Genetics. ed. H. J. Muller. Bloomington: Indiana University Press, 1962. 245-251.

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Cited as "Muller, 1950-2."

Cited as "Muller 1950-1."

NASA. "Digging in and Taking Cover." Science @NASA. 18 May, 2001.

<[http://wwwssl.msfc.nasa.gov/newhome/headlines/msad20jul98\\_1.htm](http://wwwssl.msfc.nasa.gov/newhome/headlines/msad20jul98_1.htm)>. from

<[www.nasa.gov](http://www.nasa.gov)>.

- - -. "Space Weather on Mars." Science @NASA. 18 May, 2001.

<[http://science.nasa.gov/headlines/y2001/ast01may\\_1.htm](http://science.nasa.gov/headlines/y2001/ast01may_1.htm)>. from <[www.nasa.gov](http://www.nasa.gov)>.

- - -. "The Phantom Torso." Science @NASA. 18 May, 2001.

<[http://science.nasa.gov/headlines/y2001/ast04may\\_1.htm](http://science.nasa.gov/headlines/y2001/ast04may_1.htm)>. from <[www.nasa.gov](http://www.nasa.gov)>.

- - -. "The Solar Wind at Mars." Science @NASA. 18 May, 2001.

<<http://science.nasa.gov/headlines/y2001/ast31jan%5F1.htm>>. from <[www.nasa.gov](http://www.nasa.gov)>.

Nielsen, Claus. Animal Evolution. New York: Oxford University Press, 1995.

"Radiation and Long-Term Space Flight: Ionizing Radiation's Affects on Humans." The National Space Biomedical Research Institute. 18 May, 2001.

<<http://www.nsbri.org/Radiation/HumanAffects.html>>. from <[www.nsbri.org](http://www.nsbri.org)>.

"Radiation and Long-Term Space Flight: What is Ionizing Radiation?." The National Space Biomedical Research Institute. 18 May, 2001.

<<http://www.nsbri.org/Radiation/IonizingRadiation.html>>. from <[www.nsbri.org](http://www.nsbri.org)>.

Shull, George Harrison. "Beginnings of the Heterosis Concept, 1948." Heterosis. ed.

John W. Gowen. Ames: Iowa State College Press, 1952. 14-48.

Strunnikov, V. A. "Nature of Hybrid Vigor (Heterosis) and New Methods For Its Improvement." Control Over Reproduction, Sex, and Heterosis of the Silkworm. ed. V. A. Strunnikov. Luxembourg: Hardwood Academic Publishers, 1995. 225-299.

Thorstensen, John R. "Magnetism and Magnetic Fields." Wilder 104, Dartmouth College.

19 January, 2001.

Wallace Bruce. "The Average Effect of Radiation-Induced Mutations on Viability in

*Drosophila melanogaster*." Evolution 12 (1958): 532-556.

- - -. "Studies on Irradiated Populations of *Drosophila melanogaster*." Journal

of Genetics 54 (1956): 280-293.

- - -. "Genetic Changes in populations under Irradiation." American Naturalist 85 (1951):

209-222.

Works Consulted

Cullen, Kevin. "Perdue Team Maps Out Mission to Mars." Lafayette Journal and Courier  
18 April, 2001. 18 May 2001 <<http://www.lafayettejc.com/news0418/0418104.shtml>>.

Dobzhansky, Theodosius, et al. Evolution. San Francisco: W. H. Freeman and Company,  
1977.

-- -. Evolution, Genetics, and Man. New York: John Wiley and  
Sonsm, Inc., 1955.

Manwell, Clyde and C. M. Ann Baker. Molecular Biology and the Origin of Species:  
Heterosis, Protein Polymorphism, and Animal Breeding. Seattle: University of  
Washington Press, 1970.

Rife, David C. Hybrids. Washington D. C.: Public Affairs Press, 1965.

Smith, Edward J. "Magnetic Field Measurements Near Mars." Science 149 (1965): 1241-  
1242.

Suomi, V. E., L. A. Sromovsky, and H. E. Revercomb. "Preliminary Results of the  
Pioneer Venus Small Probe Net Flux Radiometer Experiment." Science 205  
(1979): 82-83.

Waldrop, M. Mitchell. "Space Science Looks to the Future—Cautiously." Science 241  
(1988): 162-163.