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Research Paper

Misleading Geophysical Arguments from *Uranium Mining in Virginia*

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ABSTRACT:- A 2012 National Research Council (NRC) report on uranium mining in Virginia contains multiple references to "steep hurdles to be surmounted" for uranium to be safely mined in the Commonwealth. The report repeatedly refers to "extreme" climatic events, primarily those responsible for producing historical Virginia floods, two of which were associated with near-record rainfall over the lower 48 states. The NRC report also emphasizes potential seismic hazards in the Commonwealth. However, had the NRC report compared the climate and the seismic characteristics near the only economically viable deposit in the state (Coles Hill, Virginia, a location where a uranium mining and milling operation is being considered) to other areas where uranium has been successfully mined and/or processed, it would have concluded that the geophysics in the local vicinity of Coles Hill are rather benign compared some of these other locations both in the U.S. and worldwide. Further, had the NRC report examined the impacts of anthropogenerated climate change, it would have concluded that the level of threat, even under worse case scenarios, does not rise to jeopardize a well-planned and properly designed mine and tailing storage facility at Coles Hill.

KEYWORDS:- Uranium mining, tropical cyclones, floods, climate change, Virginia climate

I. INTRODUCTION

In 2012, the National Research Council (NRC) published *Uranium Mining in Virginia: Scientific, Technical, Environmental, Human Health and Safety, and Regulatory Aspects of Uranium Mining and Processing in Virginia* (hereafter, "UMV"), an extensive report that figured heavily in the debate over a legislative proposal to lift a moratorium on uranium mining in Virginia. The following summary statement appears repeatedly in the document:

If the Commonwealth of Virginia rescinds the existing moratorium on uranium mining, there are steep hurdles to be surmounted before mining and/or processing could be established within a regulatory environment that is appropriately protective of the health and safety of workers, the public, and the environment. There is only limited experience with modern underground and open pit uranium mining and processing practices in the wider United States, and no such experience in Virginia.

The body of the text repeatedly refers to "extreme" climate-related events (26 instances) and the notion of "extremes" was common in public discourse, as a reason to keep the moratorium in place. In town-hall meetings, newspaper editorials, and news stories, the specter of contamination of the water supply of Virginia Beach (175 air-miles distant from the nearest economically-viable uranium deposit) by a flood-induced tailings impoundment failure was raised repeatedly. Eventually, the proposed legislation was withdrawn because of a lack of majority support in the State Senate Committee to which it was assigned.

The legislative proposal to lift the uranium mining moratorium in Virginia was sought by Virginia Uranium Inc. (URI) as the first step in a process to develop plans for a mining and milling operation to extract uranium ore and process yellowcake (U_3O_8) from what is the largest undeveloped uranium deposit in the United States and the seventh largest in the world (Gannon et al., 2012). The uranium deposit is located in the south-

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central Virginia piedmont about 10 miles northeast of the town of Chatham, on a property known as Coles Hill. The ore bodies were first identified in the late-1970s and contain approximately 119 million pounds of uranium oxide.

In UMV, the NRC makes little attempt to compare its geophysical analysis (climate and tectonics) of Virginia to conditions in other areas of the country or the world where uranium mining and/or processing has taken or is successfully taking place. Further, in the UMV, there is no attempt to differentiate the localized Coles Hill geophysics from those of a general survey of the state.

This paper concentrates on the limitations of the UMV's geophysical analysis and provides a more comprehensive view of the climate and tectonics of the Coles Hill locality.

II. CLIMATIC ANALYSES

As noted in the UMV, there have been some "extreme"[1] weather events in Virginia; however, virtually every location in the United States can claim some history of extreme rainfall, wind, snowfall and/or drought. In reality, the climate extremes expected at Coles Hill are much less severe than those that characterize areas both to the east (stronger tropical cyclones) and west (more severe flooding) within the Commonwealth of Virginia.

Virginia's Tropical Cyclone History, With Specific Reference to Coles Hill

In Chapter 2 of UMV ("Virginia Physical and Social Context") there are many references to floods and tropical cyclones. According to the report:

Virginia is subject to extreme weather events—hurricanes and tropical storms, thunderstorms, and heavy rainfall and snowfall. In the period from 1933 to 1996, 27 hurricanes and/or tropical storms made landfall in Virginia [the citation is given as a document from the National Weather Service office in Wakefield, Virginia], bringing with them the threats of flooding, high winds, and tornadoes.

The National Weather Service reference document is titled "Historical Hurricane Tracks, 1933-1998, Virginia *and the Carolinas* [emphasis added]."[2] A direct examination of the historical tropical cyclone tracks from the National Hurricane Center reveals that only eight tropical storms (and no hurricanes) made landfall in Virginia from 1933 through 1996; the other 19 were in North and South Carolina.[3] Thus, the UMV is inaccurate in its documentation of Virginia's general tropical cyclone history, an inaccuracy which leads to the assessment of a greater risk than is actually present in the state's existing climate.

Further, a statewide assessment of tropical cyclone landfalls does not accurately reflect the climate conditions in the vicinity of the Coles Hill uranium deposit. Figure 1 shows tropical cyclone tracks within 160 kilometers (100 mi.) of Coles Hill for 1930 through 2011. There was one Category 3[4] storm (1954 Hurricane Hazel), two Category 1 storms, and all of the other passages were either tropical storms or tropical depressions. The intensity of the tropical cyclone

[1] It was pointed out to the senior author of this paper (Michaels), that his work was one of the main citations for the characterization of Virginia's weather events as "extreme," given as "Hayden and Michaels, 2001." This document was actually an unrefereed "University of Virginia News Letter" written in 1981 called "Virginia's Climate." The only change in 2001 was to update the 30-year climate "normals" to 1971-2000.
[2] The National Weather Service document can be found at http://www.erh.noaa.gov/akq/hist.htm
[3] Historical maps of North Atlantic tropical cyclones are available from http://weather.unisys.com/hurricane/atlantic/index.php
[4] Based on the Saffir-Simpson Hurricane Wind scale as applied by the U.S. National Hurricane Center, http://www.nhc.noaa.gov/aboutsshws.php

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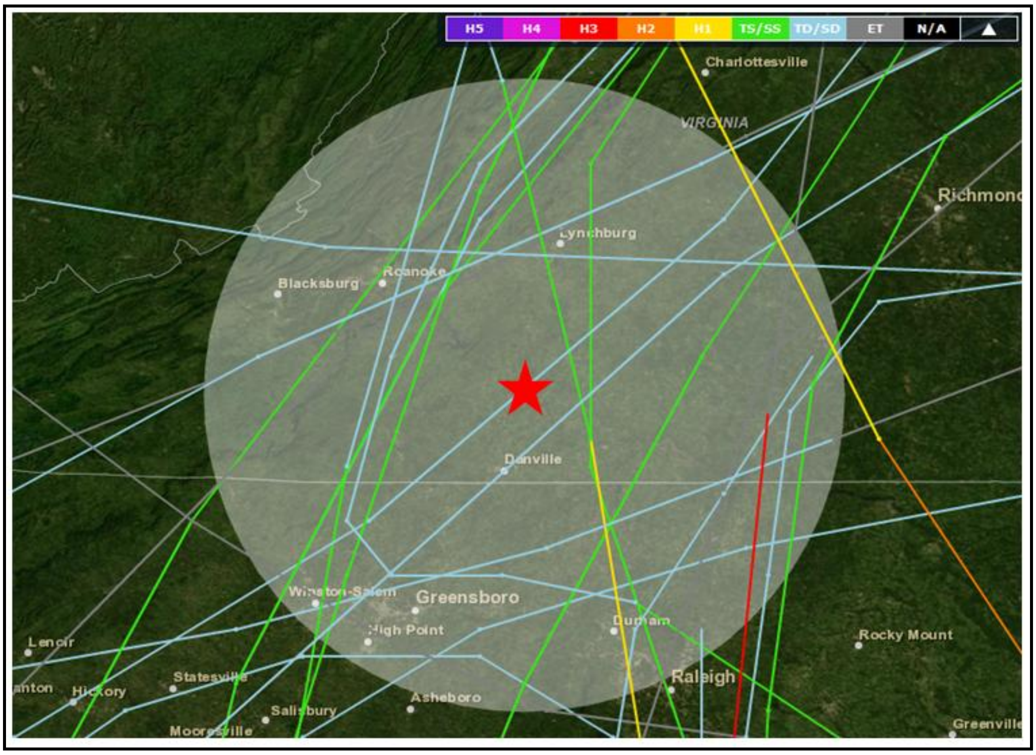

Fig. 1 Tropical cyclone tracks, 1930-2011, passing within 160 kilometers (100 miles) of the Coles Hill uranium deposit (red star). The intensity of the storm is indicated by the color of the track according to the key (H1-H5, hurricane of category 1-5; TS/SS, tropical or subtropical storm; TD/SD, tropical or subtropical depression; ET, extratropical storm; N/A, intensity not available). Of the 27 identified tropical cyclone passages, 24 were tropical storms or depressions (NOAA 2013) passages within 160 kilometers of the Coles Hill site is considerably less than for tropical cyclones making landfall along the Virginia coast.

Virginia's Extreme Flood History, With Specific Reference to Coles Hill

UMV refers to 1969 Hurricane Camille, which, while not a hurricane in Virginia, produced one of the most intense rainfalls ever measured in the coterminous U.S., saying that it "produced heavy rainfall of up to 790mm (31.1 in) as it crossed the state…"

The definitive study of the Camille rainfall was by Schwartz (1970), which states,

The greatest amount, 27 in., was measured near Massies Mill, Va. The Weather Bureau received a report of 31 in. of rain in 5 hr measured at the junction of the Tye and Piney Rivers. Since the timing of rain did not agree with other nearby reports and the catch, if verified, might be a world record, the site was visited by a Weather Bureau representative to more fully document the event. Neither the person who made the observation nor the container that was used could be identified. Therefore, the 31 in. was not used. However, a reliable measurement of 23 in. was obtained for the same general vicinity, indicating that the rainfall was extreme, and that 31 in. may have fallen.

UMV also focuses on what is known colloquially as the 1995 "Madison County Flood," a terrain-focused regenerating thunderstorm complex that produced 600mm (23.6 in.) of rain in six hours, and was accompanied by "more than 500 separate landslides, debris flows, and debris avalanches."

Conflating these two events with possible flooding and slope failure at Coles Hill ignores the fact that both of these events were topographically dependent, that the rolling, low-elevation terrain around Coles Hill is simply incapable of significantly enhancing rainfall, and that the local terrain does not have high enough relief to produce substantial debris flows. This is obvious from Figure 2, which depicts the relative topography of both of these flood sites, along with the region around Coles Hill.

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UMV notes Hurricane Fran (which was Tropical Storm Fran in Virginia) brought 400mm (15.6 in) of rain, without mentioning that the nearest weather station to Coles Hill, Chatham, VA, received only 124 mm (4.88 in.). 2011 Hurricane Irene, also noted in UMV, never made landfall in Virginia, was of no consequence in the Coles Hill region.

Our more accurate and specific analysis indicates that an extreme flood-producing rainfall event is considerably less likely for the Coles Hill location, than for other specific locations across the Commonwealth of Virginia.

III. CLIMATIC COMPARISON WITH OTHER MINED REGIONS

Tropical Cyclone Frequency and Severity

UMV's perseveration on tropical cyclones in Virginia indicates that their effects must be among the "steep hurdles" to be surmounted prior to the exploitation of the Coles Hill site. What they failed to mention is that uranium has been successfully mined and processed in other places with much more severe tropical cyclone climatologies. This includes south Texas, where the Kingsville Dome uranium operation is located only 40km from the Gulf of Mexico, two sites in the former French colony of Madagascar (Tranomaro and Folakara) from which uranium was exported in large quantities, and the Ranger Uranium Mine site in Australia's Northern Territory, one of the largest uranium mines (in terms of volume) on earth.

While the total number of tropical cyclones passing within 160 km (100 mi.) of Kingsville Dome during the period 1930-2011 (Figure 3) is virtually the same (26) as Coles Hill, the storms tend to be much stronger. More frequent and stronger tropical cyclones during this period passed within 160 km of the active and large Ranger mine in Australia (63) and over the previously mined region around Folakara, Madagascar (68). Ranger is an open-pit design that undergoes anticipated shutdowns when tropical cyclones threaten or deliver very heavy rainfall.

Peak Discharge Comparisons

Computations of predicted peak discharge for a typical 780 km^2 (300mi^2) watershed for Virginia were performed by Bisese (1995). According to the UMV "[t]hese computations show spatial variability of about a factor of six across the region for both 10- and 100-year peak discharges, with the highest peak discharges associated with watersheds draining mountainous parts of the state (e.g., Blue Ridge and Appalachian Plateau), intermediate peak discharges associated with

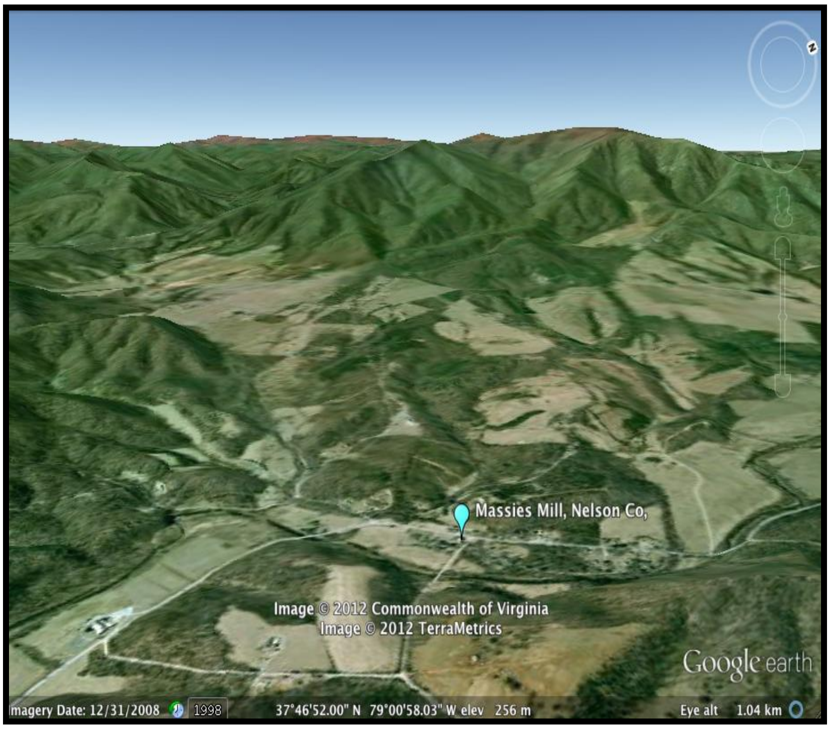

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Fig. 2 Google Earth rendering of the terrain in the immediate vicinity of (top) Massies Mill (Madison Co., VA), (middle) Graves Mill (Nelson Co., VA) and (bottom) Coles Hill (Pittsylvania Co., VA)

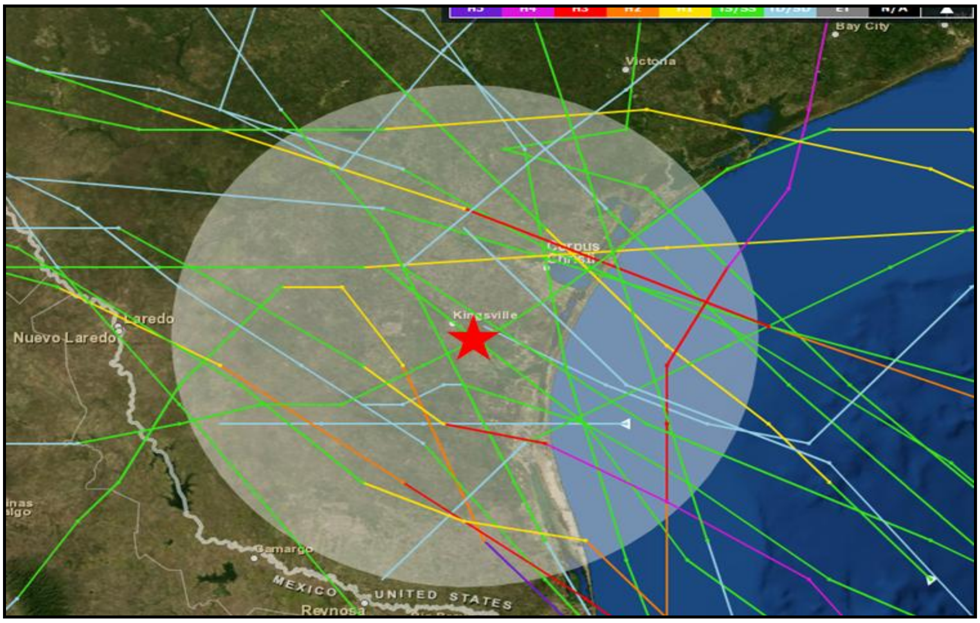

Fig. 3 Same as Fig. 1 expect for tropical cyclone tracks within 160 kilometers (100 miles) of Kingsville Dome, TX (red star). While the frequency is the same as at Coles Hill, the intensity is obviously greater (NOAA 2013)

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The Northern Piedmont and Valley and Ridge regions followed by the lowest values for the Southern Piedmont and the Coastal Plain."

Using the equations developed by Bisese (1995), the predicted peak 10-yr discharge for the Coles Hill area (in the Southern Piedmont) is 284 $m^3\ s^{-1}$/780 km^2 (10,028 $ft^3\ s^{-1}$/300 mi^2) and the peak 100-yr discharge is 583 $m^3\ s^{-1}$/780 km^2 (20,586 $ft^3\ s^{-1}$/300 mi^2). As reported in Table 1, these values are about 40 percent below the corresponding values for South Texas uranium belt (based on equations in Asquith, 1998) and considerably less than half of the same values for the vicinity of the Ranger Mine in Australia (based on equations in Taylor et al., 2011).

While UMV provides a lengthy list of Virginia floods (none of which affected Coles Hill) it neglects to place them in a national perspective. Figure 4 shows the Probable Maximum Precipitation (PMP) distributions around the coterminous U.S. east of longitude 105°W for 24-hour rainfall over 10 square miles (26 sq km) (NOAA, 1978). Again, the climatic environment is much more extreme in South Texas, where the PMP flood is near the highest in the coterminous 48 states.

Table 1. Predicted Peak Discharge Values for Streams in the Vicinity of Three Uranium-rich Sites—Coles Hill, Virginia[a]; the Coastal Texas Uranium Belt[b]; Northern Territory, Australia[c].

Region	10-Year Discharge (m^3/s)	100-Year Discharge (m^3/s)
Coastal Plain	103	211
Southern Piedmont	284	583
Northern Piedmont	480	1,078
Blue Ridge	484	1,006
Southern Valley and Ridge	345	557
Central Valley and Ridge	476	891
Northern Valley and Ridge	472	1,048
Appalachian Plateau	657	1,144
Coles Hill, Virginia	284	583
Coastal Texas Uranium Belt	472	1,087
Northwest Territory, Australia (near Ranger Mine)	682	1,519

Computations assume a typical 780 km^2 (300 mi^2) ungaged watershed located in each region.
[a] Based on equations in Bisese (1995).
[b] Based on equations in Asquith (1998).
[c] Based on equations in Taylor et al. (2011).

Uranium extraction can and does take place successfully in a more extreme hydroclimate than is characteristic of the Coles Hills region of Virginia.

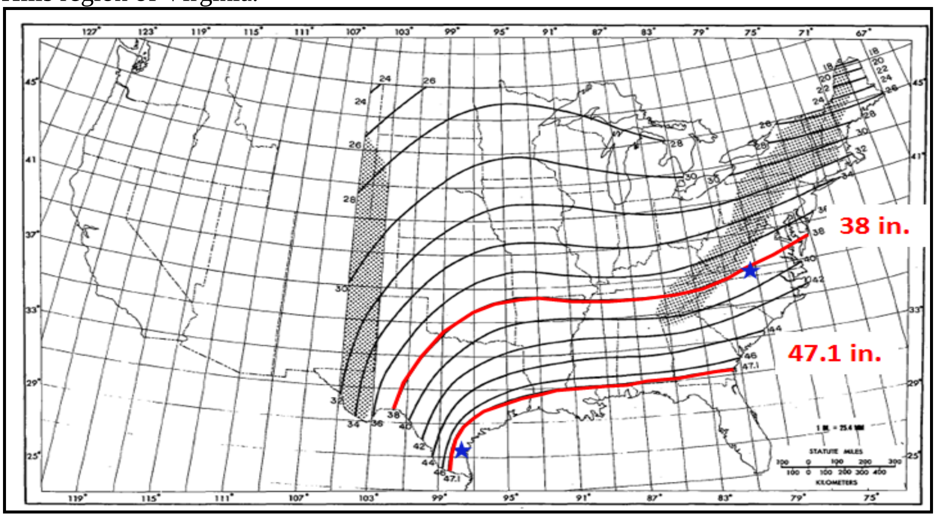

Fig. 4 24-hour Probable Maximum Precipitation. The stars indicate Coles Hill, Virginia and Kingsville Dome, Texas (adapted from NOAA, 1978)

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Probable Maximum Precipitation and Site Flooding

Kingston et al. (2011) has simulated the overland flow distribution for the 24-hour Probable Maximum Flood (PMF) at Coles Hill (Figure 5). They found that it generally follows the 180 meter (590-foot) elevation contour at this location. The current PMF is approximately 6 meters (20 feet) above bank full for the watercourse lying closest to the Coles Hill site (calculated from Kingston et al. 2011).

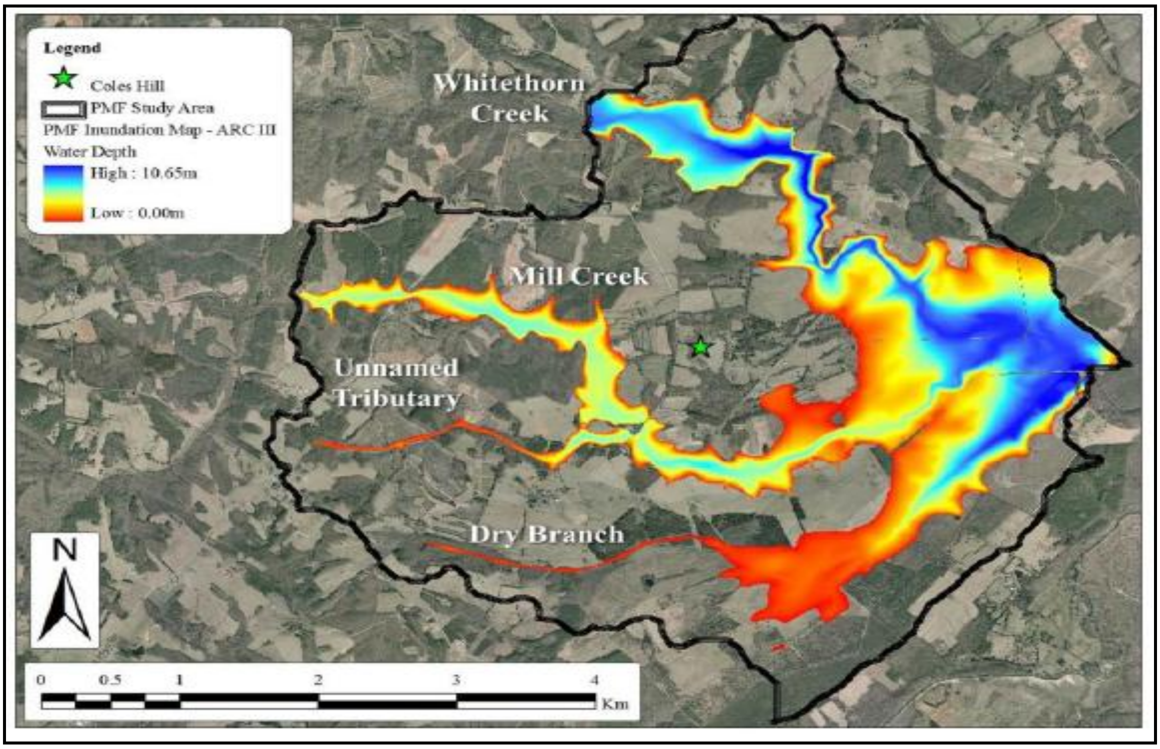

Fig. 5 Probable maximum flood (PMF) inundation map for the Coles Hill region. In the watercourse closest to the Coles Hill property, the PMF is a depth of 20 feet above bank full, and approximates the 590-foot elevation contour. Inundation of facility sited at 620 feet would likely require a flood generated by more than twice the PMP for the region (Kingston, 2011)

Probable tailings impoundments are likely in the areas of little relief on the Coles Hill property. These are approximately 190 meters (623 feet) above MSL, implying a flood depth of 10 meters (33 feet) above the current PMF would be required to flood an impoundment. Given the relatively modest relief of much of the terrain outside the immediate vicinity of the watercourses, any flood sufficient to reach the site would likely to have to be generated by over twice the current PMP. This would be a 24-hour storm with slightly more than the world's record 24-hour rainfall of 182.3 cm, (71.8 inches), at Reunion Island, on January 8, 1966.[5]
It is worth noting that the PMP in the previously-mined Madagascar sites is likely to be much closer to what has been observed at Reunion Island, which is in a climatically similar location in the West Indian Ocean.

IV. CLIMATE CHANGE AND VIRGINIA URANIUM MINING

The long-term commitment required for tailings management requires consideration of not only the current climate, but of the range of possible climate change within that long term. The specter of anthropogenerated climate change from emissions of greenhouse gases is no doubt germane to this issue.

The scientific guidance on precipitation-related issues is, at best, conflicting. Figure 6 shows projected changes for U.S. precipitation for 2080-2099 compared with the 1961-1979 average as published by the U.S. Global Change Research Program (USGCRP, 2009) under their "higher emission scenario."

[5] World record 24-hr precipitation according to the World Meteorological Organization, data available at http://wmo.asu.edu/#global

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There are several aspects of projected changes that need to be considered:

• The results are an average of 16 separate climate models. The maps are cross-hatched where two-thirds or more of the models simply project changes of the same *sign*. Under a normal binomial test, such a criterion falls outside of the ninety percent significance level for mean difference, which is hardly a stringent test.

• These results were generated under an emissions scenario that is simply not likely to occur. The scenarios were generated prior to the discovery of hundreds of years of worldwide reserves of exploitable gas-bearing shale. According to the Energy Information Administration, U.S. emissions from energy use have already dropped to 1996 levels, in large part because of fuel- switching from coal to natural gas for electrical generation, itself a result of price (and not climate change policy).[6] The U.S. has been the pioneer in exploiting this technology, which can be expected to diffuse worldwide. As a result, the precipitation changes projected by the USGCRP models can be expected to be less than those depicted in Figure 6.

• These results are produced by climate models which have an equilibrium climate sensitivity that is nearly 40 percent greater than recent estimates (Figure 7). If the climate models were adjusted to replicate the newly derived observation-based climate sensitivity estimates, the projected precipitation changes would likely be considerably less.

But even in light of these limitations, the projected precipitation changes in the vicinity of Coles Hill uranium deposit (Figure 6) are less than 10% in every season and have low confidence associated with them—an indication that based on the current climate model guidance, little change should be expected in the seasonal and annual precipitation totals there.

However, changes in annual or even seasonal totals may not be representative of changes in the frequency or the magnitude of the types of events which result in extreme flooding conditions.

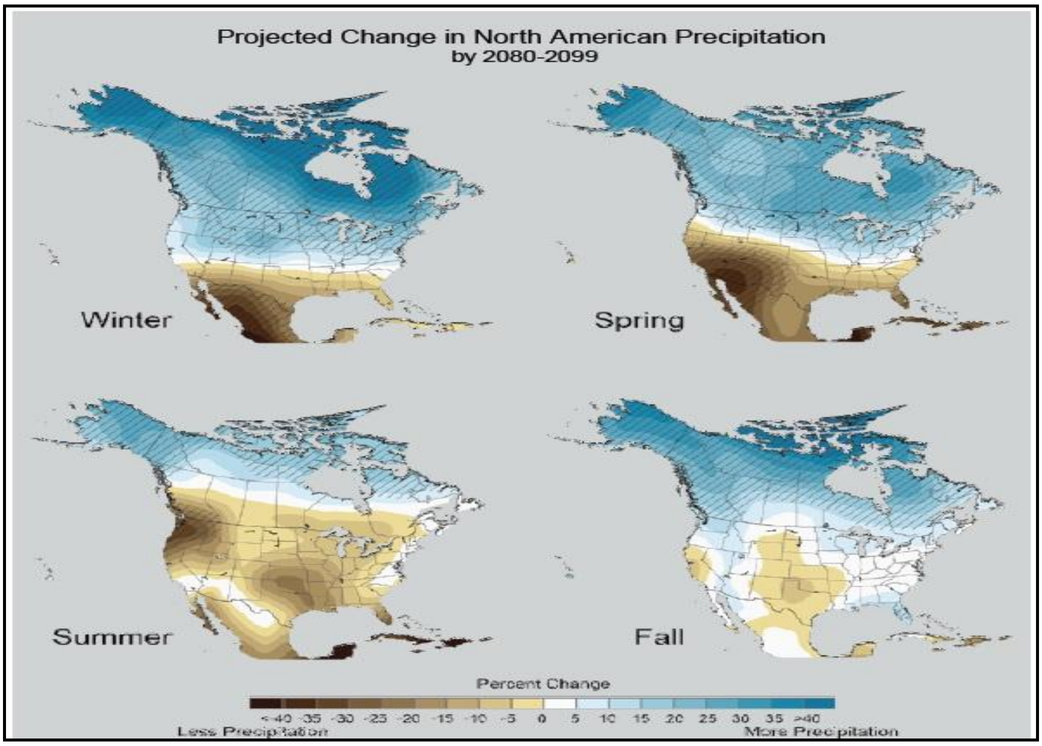

Fig. 6 Projected changes in U.S. precipitation as depicted in the Global Climate Change Impacts in the United States report. The cross-hatched areas do not meet normative criteria for statistical significance (and the non-cross-hatched areas are even less reliable). Also, the "higher emissions" scenario that drives these results was generated before the shale gas revolution, and is almost certainly wrong (USGCRP 2009)

[6] U.S. Energy Information Administration, 2012. U.S. Energy-Related Carbon Dioxide Emissions, 2011. Available at http://www.eia.gov/environment/emissions/carbon/

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The relationship between global warming and U.S. hurricanes, the presumed generator of a PMF at Coles Hill, is unclear. Several highly-cited studies have projected that global warming will lead to in increase in the frequency and intensity of the strongest tropical cyclones—including an increase in the rates of rainfall near the storms' central core (e.g., Knutson and Tuleya, 2004; Knutson and Tuleya, 2008). However, more recent studies (Murakami and Wang, 2010; Wang et al., 2011; Murakami et al., 2012) project that future climate changes will shift mean hurricane tracks further off the U.S. Atlantic coast into the open ocean, reducing the frequency of tropical cyclone landfalls. In net, this would effectively lengthen the already very long recurrence frequency of near-PMF events.

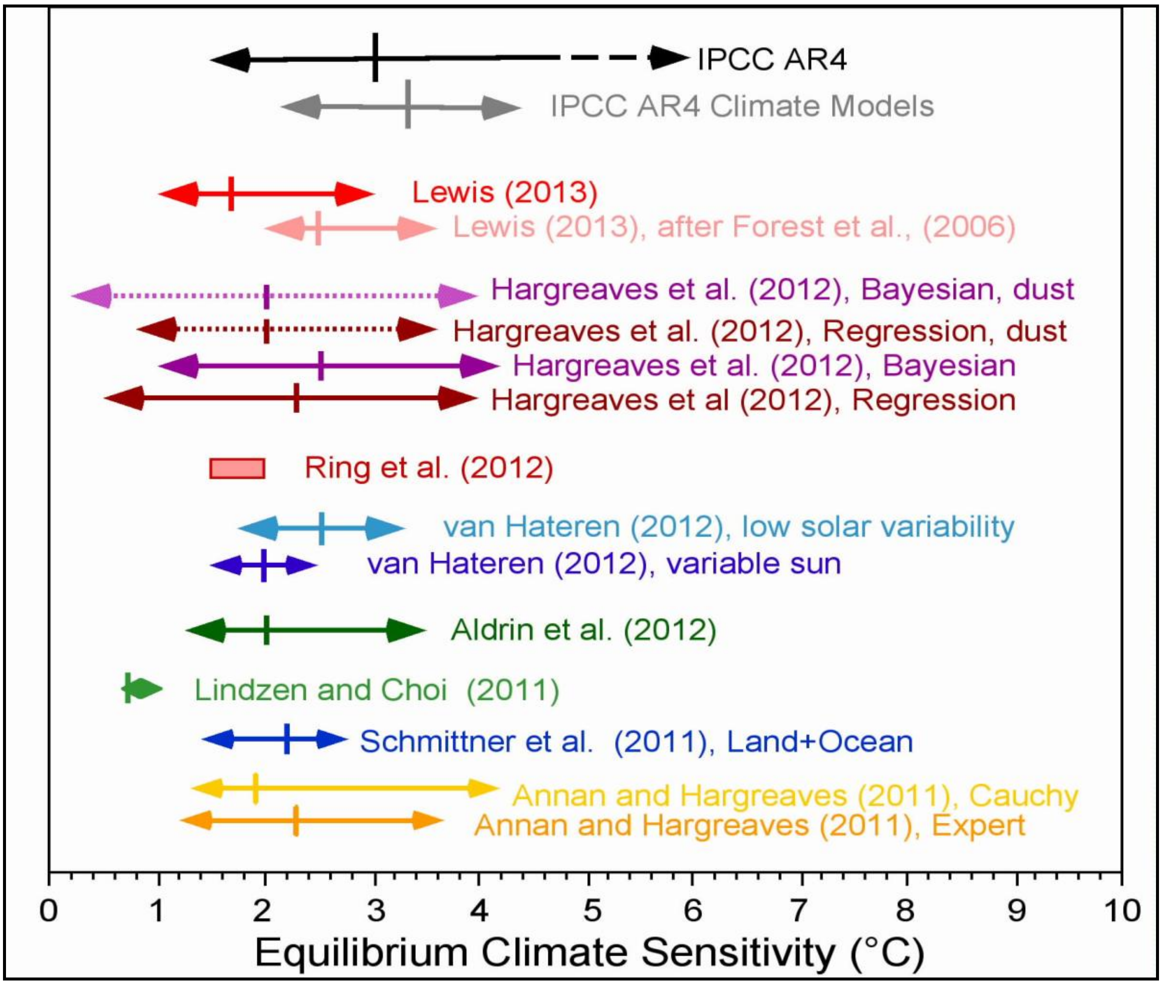

Fig. 7 Climate sensitivity estimates from new research published since 2010 (colored, compared with the range given in the Intergovernmental Panel on Climate Change Fourth Assessment Report (AR4) (black). The arrows indicate the 5 to 95% confidence bounds for each estimate along with the best estimate (median of a probability density function, except for Aldrin et al. (2012) which is the mean, or the mean of multiple estimates; vertical line) where available. Ring et al. (2012) present four estimates of the climate sensitivity and the red box encompasses those estimates. The right-hand side of the IPCC AR4 range is dotted to indicate that the IPCC does not actually state the value for the upper 95% confidence bound of their estimate, and the left-hand arrow only extends to the 10% lower bound as the 5% lower bound is not given. The mean climate sensitivity (3.3°C) of the climate models used in the IPCC AR4 is greater than the IPCC's "best estimate" of 3.0°C

The impact of rising temperatures on the PMF in the Coles Hill region can be approximated by exploiting the relationship between temperature and maximum atmospheric moisture. PMF is strongly dependent on the maximum precipitable water—which itself is closely tied to the maximum persisting 12-hour dew point temperature in the subtropical oceanic region from which moisture is advected during a PMF-producing event (for PMF calculations, see NOAA, 1978). In the case of Coles Hill this is largely bounded by sea surface temperatures (SST) off the southeastern coast of the U.S. (Maximum persisting dewpoints cannot exceed the maximum SST, or the relative humidity at the air-sea interface would exceed 100%).

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Every degree (C) rise in SST generates about a seven per cent increase in potential moisture, everything else being equal (Holton and Hakim, 2012). In this general case, a rise of 10ºC in the SST of the southwestern edge of the subtropical North Atlantic Ocean is required to double the PMF at Coles Hill.

Including convective parameters in a tropical cyclone model, Knutson and Tuleya (2004) calculate a 12 percent per ºC increase in the core rainfall rate of tropical cyclones—an indication that environmental changes in addition to an increase in surface temperature are involved in tropical cyclone precipitation processes. Assuming that such a relationship is robust and applicable across several degrees of temperature change, this would imply that a 6ºC increase is SST could lead to a doubling of the PMP at Coles Hill.

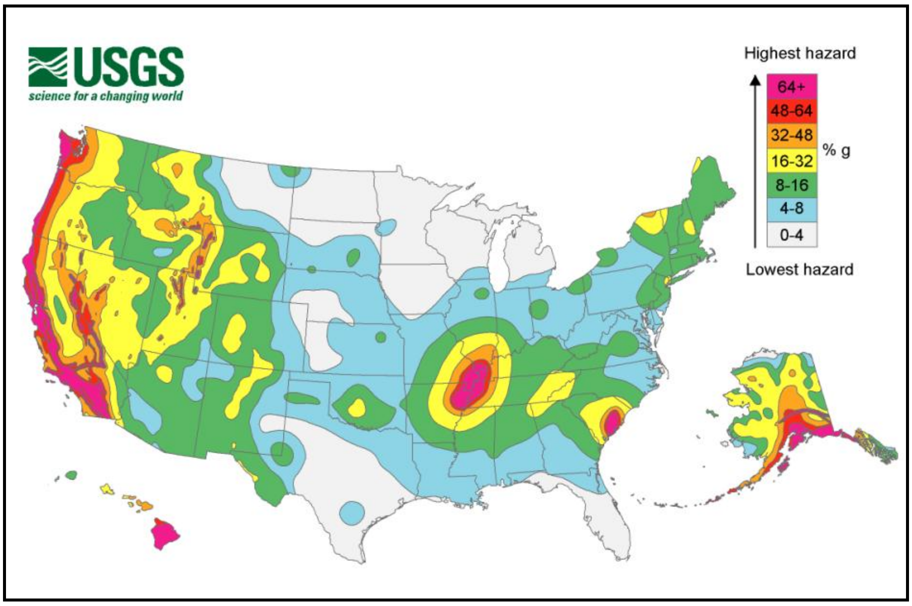
Such a warming would exceed any tropical oceanic temperature excursion of the last 100 million years. Geological data for the greatest one, the Paleocene-Eocene Thermal Maximum (PETM), 55 million years ago, suggest a sudden release of carbon thought to be roughly equal to rapidly burning all currently known carbon reserves. The concomitant rise in tropical sea surface temperatures was 4 to 5ºC (Zachos et al., 2003).

The PETM tropical SST rise is beneath that which would be required to produce a doubling of the PMP at Coles Hill, implying the burning of *more* stored carbon in fuels than are currently thought to be recoverable would be required to produce such a warming. The time required for such an enormous burn is so long as to make this speculation completely useless.

Additionally, direct examination of climate model projections under a high emissions scenario project an approximate 30% increase of the PMP in the Coles Hill region during the 2071-2100 averaging period (Kunkel et al., 2013). This value is still three times lower that that required to produce flooding at the Coles Hill location and is subject to the same caveats described above concerning the unrealistic emissions scenario and the significant overestimation of the climate sensitivity—which together certainly lead to an timeframe that is much too rapid for the PMP changes described by Kunkel et al. (2013).

V. SEISMICITY AND GEOLOGICAL HAZARDS

UMV discusses Virginia earthquakes in their section entitled "Geological Natural Hazards." There are two active seismic zones in Virginia where small to moderate earthquakes occur with some frequency. Most recently, a 5.8 magnitude temblor occurred in August, 2011, in the Central Virginia Seismic Zone (CVSZ). Shaking as a result of this earthquake was felt across the eastern U.S., most strongly near the earthquake's epicenter near Mineral, Virginia. This was the strongest recorded earthquake in the CVSZ, exceeding by 10 times the strength of the previously-recorded strongest quake—a 4.8 magnitude earthquake there in 1875. The strongest earthquake ever recorded in Virginia was a 5.9 magnitude temblor which occurred in May 1897 in the Giles County Seismic Zone (GCSZ) located in southwestern Virginia. The GCSZ is the northern end of the Southern Appalachian Seismic Zone centered in the Appalachian Mountains along the North Carolina/Tennessee Border (USGS 2012).



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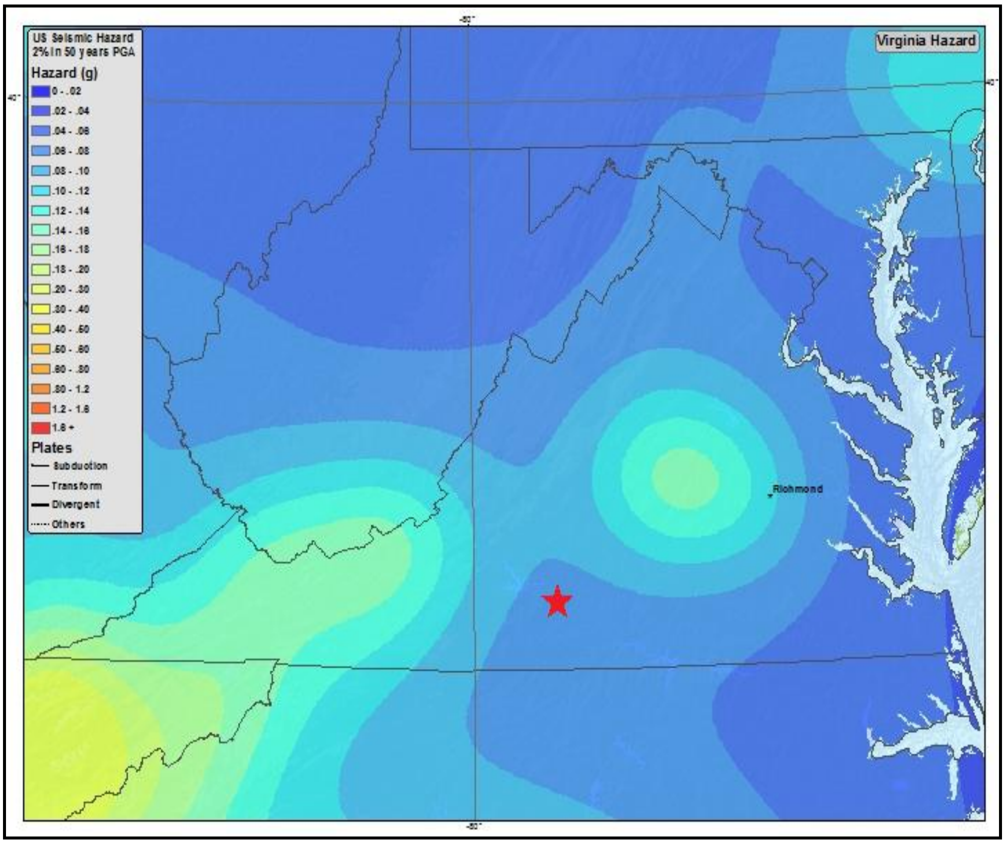

Fig. 8 National (top) and Virginia (bottom) regional seismic hazard potential. The Coles Hill region (star, lower map) is among the most inactive zones in the eastern U.S. (USGS 2008, 2012)

Coles Hill, Virginia, is not located in either of these seismic zones. Earthquake maps prepared by the United States Geologic Survey (USGS 2008, 2012) show that the earthquake risk around Coles Hill Virginia is relatively low compared with other areas of both the United States and Virginia (Figure 8). Based on models from USGS-National Seismic Hazard Mapping Project, the probability of an earthquake of the magnitude which occurred in the CVSZ in August 2011 occurring within 50 km of Coles Hill is less than 0.5% per century (or a less than 1 in 20 chance per 1,000 years).

While even moderate earthquakes are a rather rare occurrence in Virginia, landslides and debris flows resulting from extremely heavy rain events are more common in the high relief terrain of the Blue Ridge and nearby mountains (as observed in the Camille and Madison County events). It has been calculated that the return interval for debris-flow in mountainous river basins in the Blue Ridge/Appalachian Mountains in Virginia to be not more than 2,000 to 4,000 years (Eaton et al., 2003). However, catastrophic debris-flow events pose little to no risk in the Coles Hill region, as it is far removed from mountainous terrain. Locally, there is insufficient regional relief to generate large-scale flows and minimal orographic forcing for extreme rainfall.

VI. CONCLUSION

The public discussion surrounding the proposed lifting of a moratorium on uranium mining in Virginia conflated the 26 references to Virginia's "extreme" climate with the "steep hurdles to be mounted before mining" noted in UMV. This was certainly one factor involved in the Virginia legislature's failure to lift the moratorium on uranium mining.

In fact, the local climatology of the only economically viable uranium deposit in the state, at Coles Hill, near Chatham, Virginia, is not conducive to the types of "extreme" weather events that are possible in other portions of the Commonwealth of Virginia. Nor is the local climate of the Coles Hill region remarkable in comparison to other regions where uranium has been successfully mined and/or processed. It was surprising that there are so many references to "extreme" climate in Virginia without a substantial comparative analysis. Further, our analysis demonstrates that even a worse-case climate change driven by anthropogenic alterations to

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the composition of the atmosphere will not produce a climate that is "extreme" enough to produce a probable maximum flood event of sufficient magnitude to produce flooding at the site of the Coles Hill uranium deposit. Finally, UMV should have noted that the seismic "natural hazard" in Virginia is certainly *de minimus* as far as the region surrounding Coles Hill is concerned.

In summary, while UMV provided a survey of the geophysical hazards for the Commonwealth of Virginia, it did not provide a focus for the Coles Hill region, the location of the only viable uranium deposit in the Commonwealth and the location where a uranium mining and milling operation is being considered. Under such a focus, the steepness of the "hurdles to be mounted" is greatly reduced.

ACKNOWLEDGEMENTS

The use of the senior author's unrefereed 1981 publication as a primary climate citation in UMV was drawn to his attention by Walter Coles of Virginia Uranium Incorporated, which has in the past donated to the Cato Institute.

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