Geological Hazards of the Bataan Nuclear Plant: Propaganda and Scientific Fact

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14 November 2016

Introduction

The first version of this scientific review was written for general distribution in July 2010. Its facts remain valid, but aspects of two subsequent events must now be incorporated. The first is the Fukushima Daiichi nuclear disaster in Japan, triggered by a tsunami generated by the magnitude Mw 9.0 Tōhoku earthquake on 11 March 2011.

On 23 July 2012 the Fukushima Nuclear Accident Independent Investigation Commission reported[1] that the causes of the accident were foreseeable, but that Tokyo Electric Power Company (TEPCO) had not met basic safety requirements: proper risk assessment, measures to contain collateral damage, and appropriate evacuation planning.

Then, on 12 October 2012, TEPCO admitted that it had not taken these necessary measures for fear of inviting lawsuits or protests.[2] We must take the lessons of Fukushima to heart. If the Japanese, with their much more developed culture of safety, can fail so badly, what does this bode for the Philippines? Pertinent aspects of the Fukushima disaster as they apply to BNPP will be discussed throughout this report.

The second important development after my July 2010 report was the detailed geological field work on the BNPP by Dr. Mahar Lagmay and his students and colleagues. This work was published by the prestigious Geological Society of London[3]. It establishes beyond doubt that an active fault, the Lubao Fault, passes from the municipality of that name through Natib Volcano to the BNPP site at the coast. Pertinent parts of that publication will be incorporated here where appropriate.

The activation of the Bataan plant poses the greatest threat to the well-being of the Filipino people and their environment in my three decades of natural-hazard scientific experience. And the natural dangers are being greatly compounded by nuclear proponents of great influence who know little geology. They select "facts" that defend the safety of the plant site, and ignore "inconvenient" scientific truths that are easily available and verifiable. This is not only dismissive of the dangers to the people, it is a great disrespect and disdain for natural-hazard science.

Foremost among these BNPP advocates is former Congressman Marcos Cojuangco, the author of the first House bill in 2008, HB4631"Mandating the Immediate Rehabilitation,

Commissioning, and Commercial Operation of the Bataan Nuclear Power Plant". His Explanatory Note for the bill displays a glaring lack of information about the geological hazards. He knew so little about volcanoes that in his Bill he located Natib volcano "ten kilometers (10 km) from the BNPP".

Mt. Natib constitutes more than the entire northern half of the Bataan Peninsula (Figure 1). Its base is below sea level. The BNPP site is on the flank of the volcano, at Napot Point. Like Mt. Pinatubo, this volcano is "calderagenic", meaning that its eruptions are characteristically widely separated in time, but very violent, and leave a large *caldera* or depression at its summit. Natib has two calderas; one elongated in the north-south direction, 7.5 kilometers long by 5 kilometers wide. It has a second, circular caldera, 2 kilometers in diameter, about the same size as the one produced at the Pinatubo summit during its 1991 eruption. If caldera size is a measure of eruption power, the one that produced the large Natib caldera was much stronger than Pinatubo 1991.

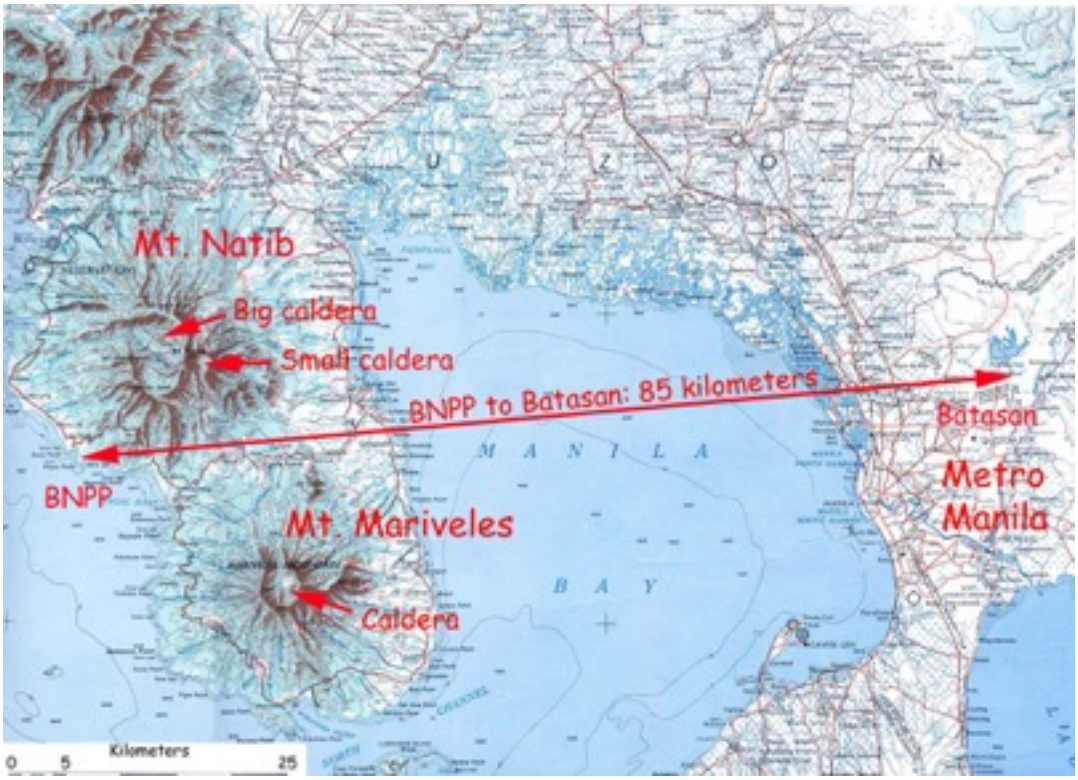

FIGURE 1. The Bataan peninsula is entirely composed of two large volcanoes. More than half, its northern part, is Mt. Natib; the southern portion is Mt. Mariveles. Mt. Natib has two "calderas" or large depressions at its summit. The older one is 5 x 7 kilometers in size and drains westward into Subic Bay. The younger one is smaller and circular, 2 kilometers in diameter, similar in size to the one formed on Pinatubo during its 1991 eruption.

Another "must read" by conscientious proponents, and anyone who simply wants to know the scientific facts, is the June 25, 2005 Council on Foreign Relations discussion, "Are Nuclear Spent Fuel Pools Secure?[4]. Quoting that report:

"Nuclear fuel becomes spent, or used, after it has been in a reactor for between about 4.5 and 6 years. The fuel is not actually exhausted at this point, but is no longer an economically viable heat source. Every 18 to 24 months about a third of the fuel of an operating commercial nuclear reactor is removed. The fuel is highly radioactive and continues to produce a large amount of heat through radioactive decay, called 'decay heat,' after its removal."

The spent fuel rods must be kept immersed in a pool of water, typically 40 by 40 feet in area and 40 feet deep, in which the radiation from the rods is absorbed and transformed into heat. Millions of gallons of water must flow through the plant every day not only to cool the reactor core, but also the spent-fuel pool. Even if an eruption were predicted in time to shut the reactor down, it would not be possible to evacuate the spent fuel rods. Interruption of that water supply could be catastrophic, as occurred at Fukushima in 2012.

A disruption would not be very difficult: Failure of a pump or valve, rupture of a pipe, an inattentive or sleepy technician, an electrical brownout or power surge… Not much of a task for an even moderate earthquake, let alone an eruption. Taiwan scientists Chang-Hwa Chen and J.J.-S. Shen have pointed out that undersea volcanic eruptions generate large quantities of floating pumice that could easily clog the seawater intakes of nuclear plants[5]. Huge quantities of low-density pumice fell on Zambales, Bataan and Subic Bay during the 1991 Pinatubo eruption, and we are very fortunate that the BNPP was not operating.

The spent fuel rods are armored with a zirconium alloy. If the pool water were lost, the armor of the newest spent-fuel assembly would ignite, and in turn could ignite adjacent fuel assemblies. Once started, the fire would be virtually impossible to put out. Spraying it with water would only make it worse, because even more heat is generated when zirconium reacts with steam. A fire and explosion in the spent fuel storage pool could release huge volumes of radioactive gases to the atmosphere, including much radioactive cesium-137, which is water-soluble and extremely toxic in minute amounts.

An aside: As a Zambaleño and friend of Olongapo and the Subic Bay Metropolitan Authority, I am concerned about the impact of millions of gallons of seawater heated and released every day, on Subic Bay and adjacent coastal environments and ecosystems should BNPP be operated. Does an Environmental Impact Statement for BNPP include an evaluation of such questions?

Propaganda

Mr. Cojuangco must have learned a few things from the seminars on nuclear power he attended early in 2010 at the National Institute of Geological Sciences. He stopped

repeating some of his many naïve but widely proclaimed ideas, for example, that the BNPP is more than ten kilometers away from Mt. Natib.

But the Congressman was bound and determined that the plant must be refurbished and operated, come what may, so it is left to others to declare the safety of the site. Most of these nuclear apologists, including prominent media commentators and government figures, clearly know no more geology than the congressman does, and repeat many of his naive statements, including some that he has abandoned.

For example: Cojuangco's mistaken notion that the farthest a volcanic mass can travel is six times the elevation of the volcano has frequently been referred to by newspaper columnists and TV commentators. Geologists will recognize this as a misuse of a ratio that they use to estimate how far a landslide can travel. During an eruption, *pyroclastic flows* --- dense mixtures of explosion debris and very hot gases -- can surge great distances down the volcano flanks at hurricane speeds, searing and obliterating everything in their paths. These are not landslides!

We have documented[6] one such prehistoric pyroclastic flow from Mt. Natib that entered Subic Bay sometime between 11,000 and 18,000 years ago. Contrary to Mr. Cojuangco's misreading of our research, that event can by no means be assumed to have occurred during Natib's latest eruption.

Some history

A much more thoughtful Congressman, Hon. Roilo Golez, has cautioned that the risks are magnified by a national lack of a "culture of safety that is observed in Japan, the United States and Western Europe". The BNPP has been cursed with that lack from the very beginning. It continues to this day.

The casual dismissal of the geohazards at Napot Point by Cojuangco and other nuclear proponents carries on the tradition of hurried carelessness exercised by the dictator Ferdinand Marcos, who decided to build nuclear reactors in 1973 and forced the construction to begin in 1976, even before the natural hazards had been properly assessed. That task should have taken at least five years, but dictators are not patient. That task remains unfinished to this day.

The Hernandez-Santos 1977 report

On 12 January 1977, after the BNPP construction had already started, Nuclear Technologist III Elmer C. Hernandez and Senior Nuclear Technologist Gabriel Santos, Jr. submitted an 8-page internal report on the geohazards at the BNPP site[7]. Hernandez and Santos were true heroes, their concern for the well-being of the public outweighing the risk of dictatorial displeasure. Excerpts from that report are alarming:

"1. The proposed site … is very near the Manila Trench – Luzon Trough tectonic structures.

"2. The proposed site is literally bracketed by significant and very strong (high magnitude) historical earthquakes…within a 100 kilometer radius. In fact…one … occurred (1970) within 1-2 km of the proposed site itself in Napot Point.

"3. The probability of an epicenter of an earthquake occurring at the site is unacceptably very high. Covering a span of 74 years, 49 significant earthquakes occurred in the above area, one of which one occurred within 1-2 kilometers of the proposed site itself. …"

"4. Known significant and major earthquakes with magnitudes greater than 8 were apparently overlooked and not considered in the computation of the shutdown earthquake design basis...

"5. Earth satellite data… suggest the presence of a lineament in the site itself. Ground magnetometer data… appear to substantiate the existence of a probable fault at the proposed plant location."

Hernandez and Santos concluded: "… The above review has revealed the high risk potential for the protection of health and safety of the public if the proposed site is accepted. High probability earth motions associated with earthquakes due to the Manila Trench – West Luzon Trough displacements and presence of a probable fault in the plant location itself may lend to structural failures causing the release of radioactive materials from the nuclear power plant or may cause extensive damage to the plant."

But Marcos was not to be denied, and the construction continued.

The 1979 Sonido report

Nevertheless, the Philippine Atomic Energy Commission must have been concerned enough to ask Prof. Ernesto Sonido, the geophysicist of the UP-Diliman Department of Geology and Geography, to investigate the site further. On 25 January 1979 he submitted his report to PAEC[8].

Apparently, NPC had cut trenches through a postulated fault and reported no evidence of faulting in them "without considering the difficulty of detecting faults in thick overburden and easily 'healable' rocks exposed in the trenches."

Dr. Sonido mentioned numerous mistakes by NPC, including a 90° error in the given direction of a trench. He also remarked several times that much field information had already been destroyed or obscured by the ongoing construction.

Nevertheless, Dr. Sonido and Mr. John Palmer, the groundwater consultant of the contractor firm Ebasco, agreed on site that "the postulated fault is a fault zone with a width equal to the width of [a] river [south of Napot Point?] and that the existing river is along the fault..." Numerous seepages along fractures in otherwise impermeable rocks, and variable depths of a 'tuff' horizon in more than 30 boreholes at the plant site "…suggest that the area had been tectonically active…".

The Post-Chernobyl Government Studies of the BNPP

After the Aquino administration mothballed the nuclear plant following the Chernobyl disaster, the Presidential Committee on the Philippine Nuclear Power Plant (PC-PNPP) commissioned NUS Corporation, a U.S. nuclear consultancy firm, to manage a technical audit of the BNPP. NUS assembled a multidisciplinary team of over 15 nuclear experts from the US, Germany, Brazil, South Korea and Japan to evaluate the field implementation of the plant design, quality assurance and control, and construction practices.

A technical audit of the BNPP was also commissioned by a Senate Ad-Hoc Committee on the BNPP. From 1988 to 1990 over 50 nuclear experts from the US and Europe made a much more extensive audit that cost the government $10 million. The study was kept confidential because of the pending litigation vs Westinghouse, who constructed the plant. Its many volumes remain locked up in the Senate vaults.

According to Nicanor Perlas, who was a technical consultant for both studies, the experts concluded that the project's Quality Assurance Program was sloppy and below regulatory standards[9]. Thus, it was impossible to determine if the strict specifications for constructing a nuclear plant were met.

Perlas says that the studies should be made fully available to the public to save much unnecessary and expensive duplication. After all, the Filipino taxpayers paid for them, and are entitled to their full perusal and proper use.

But in 2009 it turned out, mysteriously, that neither the Senate nor Malacañang could find the voluminous reports of these studies[10].

The 1986 Fortune Magazine *article*

Fortunately, many of the details in those missing reports should contain were published by *Fortune Magazine* in 1986[11], while memories of the the BNPP project were still fresh. Anyone who wishes to comment on the safety of the BNPP owes it to the public to read it.

The article relates in horrifying, sometimes amusing detail, the feeding frenzy of American companies and Marcos cronies alike, over the billions of dollars involved. It also tells how "… in March 1976, Westinghouse began clearing the site before Napocor had a construction permit from the Philippine Atomic Energy Commission", and how Ebasco contractors "were still performing on-site tests to determine whether the site was safe.

"... The work began so early that the bulldozers rumbling around the site interfered with the seismic tests… Librado Ibe, the Philippine regulator, says Westinghouse rushed into construction because National Power and Marcos wanted the plant built quickly."

Apologists now deny the numerous allegations of carelessness during construction. But the *Fortune* article also details serious quality issues that were raised by IAEA technicians. Please keep in mind how spent-fuel pools need large flows of cooling seawater, as you read this long excerpt:

"Of the experts who were at the plant during construction, the most persuasive witness is William Albert, the IAEA adviser. Albert spent 18 years with the NRC and its predecessor, the U.S. Atomic Energy Commission, before retiring this year. NRC safety specialists describe him as one of the best inspectors the agency ever had. He spent 3 1/2 years in the Philippines -- from July 1979 to July 1981 and from October 1983 to March 1985.

"Westinghouse itself recommended Albert to FORTUNE as a competent expert who paid close attention to what happened at the plant. Albert does not say the plant is hopelessly flawed. Indeed, he argues that Aquino should fix it and put it in operation. But he says it could conceivably cost hundreds of millions of dollars to do that. To know for sure, he says, would require a detailed inspection by a team of 40 to 50 specialists.

"One major problem Albert describes involves welds in a system of thousands of hangers for water pipes that snake throughout the plant. A badly welded hanger could allow a pipe to burst, causing a major accident or the failure of an essential safety system. The welders at the Philippine plant, Albert charges, broke many rules of the trade.

"Welders use a metal called weld rod, which in humid Bataan must be kept dry because moisture can cause a seam to crack. To keep the rod dry, welders store it in a small, box-shaped electric oven that is supposed to be plugged in at all times. But the welders at the plant often played a game: They would see how long they could fool inspectors by keeping their ovens unplugged. Albert says the welders did not want to bother stringing extension cords to the ovens.

"Albert adds that welders worked around the clock when Westinghouse sped up construction at the plant. He came upon one welder who had been on the job for 26 hours. 'They let me get an hour of sleep now and then,' the worker explained. Says Albert: 'There's no way a welder can work for 26 hours straight and do quality work.'

"Westinghouse insists that it has checked all the welds and verified that they are fine. But that is difficult to prove since record keeping at the plant was sloppy. An inspector on the site found couplings in a cooling-tower fan that were grossly misaligned. When he checked the records, he found the paperwork for couplings that had been properly installed, but not for those that were bungled. Westinghouse concedes that quality was sometimes hard to monitor because reports were illegible.

“Albert also criticizes the work on base plates that hold pipe hangers in place. Each hanger is attached to a metal plate, which in turn is bolted to the concrete walls, ceilings, or floors. Albert says many of these plates were installed so badly that they were not flush to the surface. Bolts holding the plates frequently did not grip the concrete and twisted continuously if turned. If plates broke away from the wall during an earthquake, Albert says, pipes could fly around the plant like loose fire hoses.

“Some pipes are meant to move because they must flex as the pressure or temperature in them rises and falls. Albert says plates and hangers that are supposed to allow movement were sometimes badly aligned, preventing the pipes from shifting freely. In other instances plates designed to move were bolted fast to the floor. Albert pointed this out to Westinghouse, he says, ‘and they accepted it as is.’

“An IAEA team that inspected the plant in June 1984 noted that many valves controlling water flow were poorly marked or unmarked. Albert says the valves were still poorly marked in February 1985, after Westinghouse had pronounced the plant complete. He adds that workers blithely twisted valves with tags on them saying DO NOT OPERATE. A worker caught tampering with a valve in a U.S. nuclear plant would be fired.

“During the rainy season, underground conduits and vaults carrying electrical cables between buildings fill with water. Westinghouse says the flooding was expected and is not a problem. The cables running between buildings, it says, are designed to operate under water. Another safety expert from the IAEA who was on the scene to advise the Philippine Atomic Energy Commission disagrees. He is Lucian Vorderbrueggen, an electrical engineer who recently retired from his job as a senior safety inspector with the NRC. ‘Cable is not designed to be constantly submerged,’ he says, explaining that the insulation could eventually break down and the cable short-circuit, cutting off power to safety equipment.

“Vorderbrueggen, who was at the plant until last September, says the underground vaults were badly built and leak constantly. To repair them properly, he says, would require major redesign and rebuilding. He adds that Westinghouse did nothing about the leaking in most of the vaults, but dealt with the problem in a couple of them by trying to seal them and putting in sump pumps, which he calls ‘a real Band-Aid fix.’ Says Vorderbrueggen: ‘In the U.S. (the NRC) would say, 'Fix it right or we won't license the plant.' ‘

“Albert attributes all these problems to a breakdown in quality control. Westinghouse had a quality control staff of 45 persons at peak construction. Albert estimates that its two principal subcontractors, Disini's Power Contractors Inc. and Miescor, a company controlled by a brother of Imelda Marcos, had 40 or more. National Power had 30, plus five Ebasco experts to advise them. And the Philippine Atomic Energy Commission had two inspectors who visited the site occasionally and eight advisers like Albert who were there under the aegis of the IAEA.

“Why couldn't all those inspectors ensure that the work was done right? Witnesses disagree. Albert says Westinghouse had the final authority on how problems were resolved, and some of its inspectors would not take the necessary corrective action. ‘They couldn't have cared less,’ he says. Josue Polintan, the National Power senior vice president in charge

of the plant, agrees that quality control was poor but says the Westinghouse inspectors were not to blame. ‘If the guys at Westinghouse found out about it,’ he says, ‘they would try to fix the problems, but their workers would try to cover up and Westinghouse couldn't possibly catch it all.’

“Albert claims that Westinghouse officials routinely took too little action in response to complaints from its subcontractors and National Power inspectors. He says much of the clout National Power had came through the Atomic Energy Commission, which had the final say about whether the plant was acceptable. As a result, National Power inspectors would sometimes ask the commission to intervene when Westinghouse did not heed complaints from the utility. But even that often failed. ‘If you got Westinghouse to say they would do something, usually something would be done,’ says Albert. ‘But whether it was satisfactory was another matter.’

“In 1979 Albert reported to Westinghouse that workers were not heating high-carbon-steel reinforcing rods in the concrete structure before welding them. Failure to heat the rods increases the risk that the welds will crack. Albert says Westinghouse agreed to teach the welders how to do the job right. When he returned to the site over four years later, however, they still weren't heating the rods. ‘The only difference,’ he says, ‘was that they knew better.’

“Westinghouse appears to have solved some deficiencies by rewriting specifications. Paul van Gemst, a Swedish engineer on loan to the IAEA from ASEA-ATOM, a company that builds nuclear plants, says commission employees told him that was how Westinghouse cured the problems with the base plates for the pipe support brackets. ‘Westinghouse tried to recalculate the hangers and base plates to prove that they did meet specifications,’ says van Gemst. ‘When they failed to meet the specs, Westinghouse modified them.’ Westinghouse acknowledges that it changed specifications for base plates and hangers, but says design engineers certified that the new specs met design requirements.

“In disputing the charges of construction flaws, Westinghouse relies heavily on reports made in February 1985 by an IAEA inspection team and the Philippine Atomic Energy Commission's technical staff. Westinghouse says both groups concluded that the plant ‘meets international safety standards followed by 26 nations’ and was ready for core loading.

“The commission staff report does not provide the endorsement Westinghouse describes. The staff said that National Power and Westinghouse had all their paperwork in order, so the commission could begin considering the application for an operating license. The report added that several safety issues still had to be resolved before the nuclear fuel could be loaded.

“The IAEA report that Westinghouse cites was a follow-up to a report by another IAEA team that found a morass of defects in June 1984. ‘In the past,’ the 1984 IAEA team said, ‘quality assurance in construction work showed major weaknesses, as was indicated by generic deficiencies, which went undetected for a long time, especially in respect of welding-rod control, cable pulling, and valve installations. The result was a deterioration in the work

quality on-site.' The 1985 report indicates that the problems had been solved and concludes that 'there is no technical obstacle' to loading fuel and running the plant.

"How could two IAEA teams, both led by the agency's safety director, Morris Rosen, arrive at such different conclusions just eight months apart? For one thing, a construction expert on the 1984 team who was critical of the plant, William Ang of the NRC, was not on the 1985 team. Apart from an engineer who visited in 1984 and found some continuing problems with the electrical cables when he returned in 1985, the members of the second team were not construction experts. They specialized in such areas as training and radiation exposure.

"Albert maintains, and other NRC safety experts agree, that the IAEA team could not possibly have done a thorough inspection in the week it spent at the plant. He also says that many problems cited by the 1984 team still existed a month after the 1985 team had left. Rosen refuses to say what the second team did to reexamine the problems reported by the 1984 team. 'I won't comment on specifics,' he says. 'These are very technical. People involved at the plant say nothing was wrong with it'".

The Ruaya-Panem 1991 study of the large Natib caldera

In the late 1980s, J. R. Ruaya and C. C. Panem of the Philippine National Oil Corporation published research conducted on numerous hot springs emanating from many faults within the large Mt. Natib caldera (Figure 2)[12]. Their geochemical research indicated a subsurface heat source "greater than 200°C". This is much more activity than Pinatubo exhibited before its world-class 1991 eruption.

FIGURE 2. The summit calderas of Mt. Natib. Modified from Ruaya and Panem,1991[10].

The 1992 Torres report

In 1992, Dr. Ronnie Torres, a foremost pyroclastic-flow expert at Phivolcs, warned of volcanism and faulting at the site[13]: "Natib volcano does not erupt very often *but could still erupt* [emphasis mine]."

The Sonido-Umbal 2000 Report to the Subic Bay Metropolitan Authority

Dr. Ernesto Sonido collaborated with Mr. Jesse Umbal in 2000 to submit a detailed analysis for SBMA of the geology and geohazards of the Subic Bay area[14]. Jesse Umbal is one of the brightest, most competent volcanologists and geologists I know. Working with me during the Pinatubo eruption, he earned his Masters degree at the University of Illinois in 1993. Dr. Sonido is not a volcanologist, so we can assume that Umbal wrote those aspects in the report, which adjudged Natib as "potentially active".

The report analyzes the configurations of the two calderas at the summit of Mt. Natib, and concludes that the smaller caldera is younger, made by a later eruption, because it

disrupts the rim of the larger caldera. By the same simple reasoning, we can tell which of two overlapping footprints in mud came first and which came last.

Sonido and Umbal also studied the system of faults exposed on land in the larger region. They estimated the recurrence period for earthquakes of Magnitude 6.4 to 7.0 at 22 years; of Magnitude 7.0 to 7.3 at 59 years; and of Magnitude 7.3 to 8.2 at 157 years. Recall that the earthquake that damaged the K-KPS was only of magnitude Mw 6.6.

The Cabato et al. 2005 article

In 1997, Ms. Joan Cabato and Dr. Fernando Siringan of the National Institute of Geological Sciences at UP Diliman and I, collaborating with the Mines and Geosciences Bureau and the National Power Corp., initiated a geophysical study of the marine geology of Subic Bay (Figure 3)[6]. The study was supported as "due diligence" hazard evaluation by then SBMA Chairman Richard J. Gordon.

From a slowly moving boat or ship, we gathered 125 kilometers of "seismic reflection" data. That method puts into the water powerful pulses of low-frequency sound that passes down through it and into the layers of sediment below the sea floor. Some of the sound is reflected back upwards from the different sediment layers, and is collected by hydrophones trailing behind the boat. Much as if we took an X-ray, electronic equipment automatically uses the returned signals to make a detailed picture of the structure underlying the sea, in our case down to a depth of about 120 meters.

Our work underwent rigorous scrutiny by our geological peers in the Philippines and abroad, before it was published in the international *Journal of Asian Earth Sciences*[6]. It earned a Masters degree for Joan Cabato, a very bright young woman who went on to earn her doctorate from the University of Heidelberg in Germany.

Quite by accident, we discovered a large mass of sediment that can only be explained as the underwater deposit of a large pyroclastic flow from the large Natib caldera that occurred sometime between 11,000 and 18,000 years ago.

The Explanatory Note to Congressman Cojuangco's Bill wrongly uses that date for Natib's latest eruption:

"Top geologists have evaluated Bataan and, with the exception of Mt. Natib which is a dormant volcano whose last eruption was estimated to have been between 11.3 to 18 thousand years ago (Cabato et al. 2005) and which is ten kilometers (10 km) from the BNPP, could find no anomalies in locating the plant there."

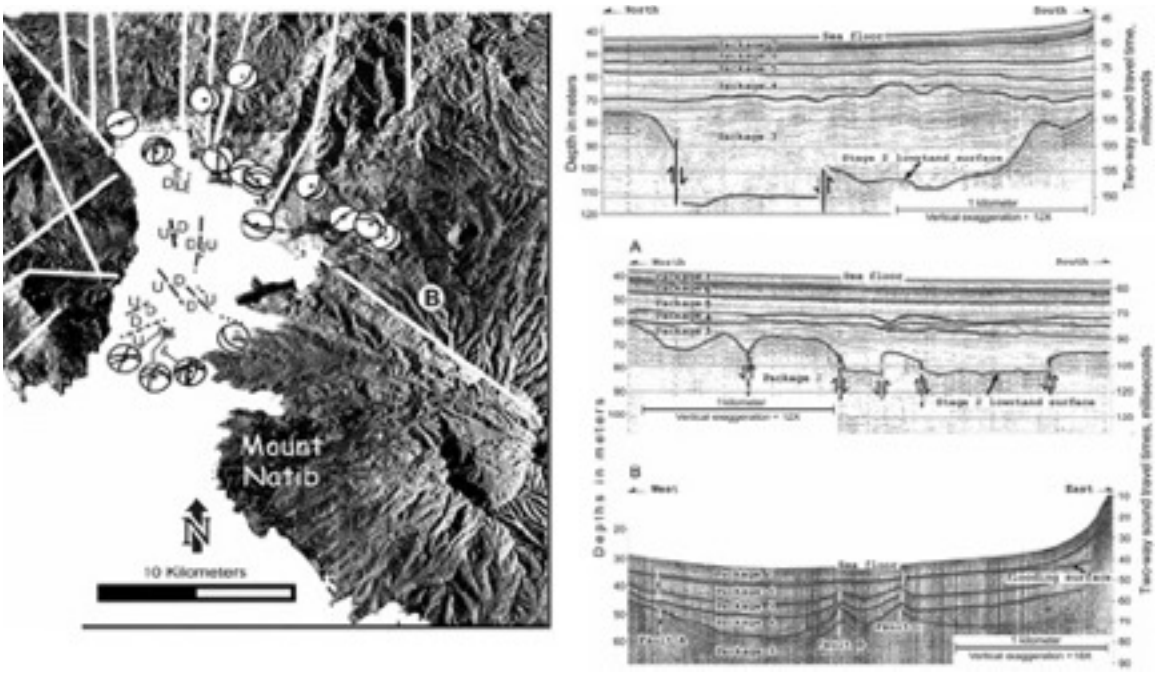

FIGURE 3. Faults and earthquakes in the vicinity of Subic Bay, northwest of Mt. Natib. Left: White lines on land are documented or suspected faults on land. Solid lines in the bay are submarine faults; the U and D notations indicate the sides of each fault that moved up or down relative to the other side. The circles denote earthquake epicenters and their senses of displacement. Right: Vertical cross sections, showing buried faults in the bay. Modified from Cabato et al., 2005[6].

A systematic study of Natib itself could find evidence of even younger eruptions. In fact, the smaller caldera disrupts the rim of the larger one, thus must have been formed by a later eruption.

Cojuangco ignored the principal finding of our survey: that faults in Subic Bay are active roughly every 2,000 years, and that the last episode of faulting took place about 3,000 years ago. When one of the faults is active, one side of it moves up or down vertically as much as 5 meters relative to the other side. Our data cannot tell how much horizontal movement occurred. We also cannot say whether such movements are rapid enough to generate tsunamis, but this is a genuine possibility.

A similar marine seismic-reflection survey needs to be conducted south of Subic Bay and Mt. Natib, to determine the presence or absence of similar faults. My understanding is that UP professors Mahar Lagmay and Fernando Siringan have proposed to conduct this work. In March, 2009 Congress approved a bill designating P100 million for such studies, but the funds did not materialize, or were instead given to the KEPCO, the Korean Electric Power Company, which operates two reactors sister to BNPP and offered to renovate it. Without funding, Dr. Lagmay and other volunteer geologists studied the environs of BNPP exhaustively and have documented much evidence for faulting there[3].

Faulting and earthquakes: Propaganda about BNPP

Widely publicized statements by Cojuangco and his allies declaring the BNPP site to be fault-free and therefore safe are not only wrong, they dangerously mislead the general public about the earthquake hazard. In the first place, as I will show, the active Lubao Fault runs from the municipality of that name through the entire body of Natib Volcano and emerges at the Natib Point site of the BNPP. Secondly, the nuclear plant could easily be damaged by faulting far from it.

Much of Cojuanco propaganda is based on statements by Dr, Carlo Arcilla, until recently the Director of the National Institute of Geological Sciences at UP Diliman. Arcilla is not only my colleague, but an old friend and former student as well. I served on both his Masters and Doctoral committees at the University of Illinois at Chicago. But our relationship is far outweighed by the safety of many Filipinos, and by my commitment to the honest use of science. Dr. Arcilla's statements, although seriously mistaken, carry undeserved weight to this day, by virtue of his having been UP-NIGS Director.

Arcilla first publicly and categorically declared that the BNPP was safe and had no fault near it before he even knew where the plant was situated, in a presentation at the June 2005 Asia Oceania Geosciences Society meeting in Singapore. It can be accessed on the Internet[15]. Slide 30 of that presentation says: "No direct evidence of fault running across facility" and "Latest satellite data suggest also no large structures directly located at nuclear plant".

But on his Slide 34, based on a terrain diagram he acquired from Prof. Mahar Lagmay that is supposed to back up those statements, he mistakenly located the BNPP about 8 kilometers up the coast (Figure 5). The red lineaments in the diagram are suspected faults; the westernmost one *passes right through* the correct Napot Point site. This is may be the same one referred to in 1977 by Hernandez and Santos[7] and by Sonido in 1979[8], now verified as the Lubao Fault of Lagmay wet al.[3].

The diagram also erroneously locates Pinatubo much too far to the south. Pinatubo does *not* abut Natib and drain into Subic Bay; the volcanoes are separated by about 17 kilometers of intervening Quaternary volcanic terrain, which in the diagram is mistakenly labeled as Pinatubo.

Arcilla showed his predisposition in favor of the BNPP in an *Inquirer* interview[16] he gave Ms. Tonette Orejas on January 21, 2009 when he accompanied Cojuangco to the Congressional "ocular inspection" of the BNPP.

"Arcilla, director of the National Institute of Geological Sciences at the University of the Philippines in Diliman, Quezon City, said the BNPP is not located near a fault."'There is

no fault near here,'" Arcilla said, addressing an important issue that had hounded the BNPP since its construction in 1976.

"An independent study he is starting would confirm that information, Arcilla said.

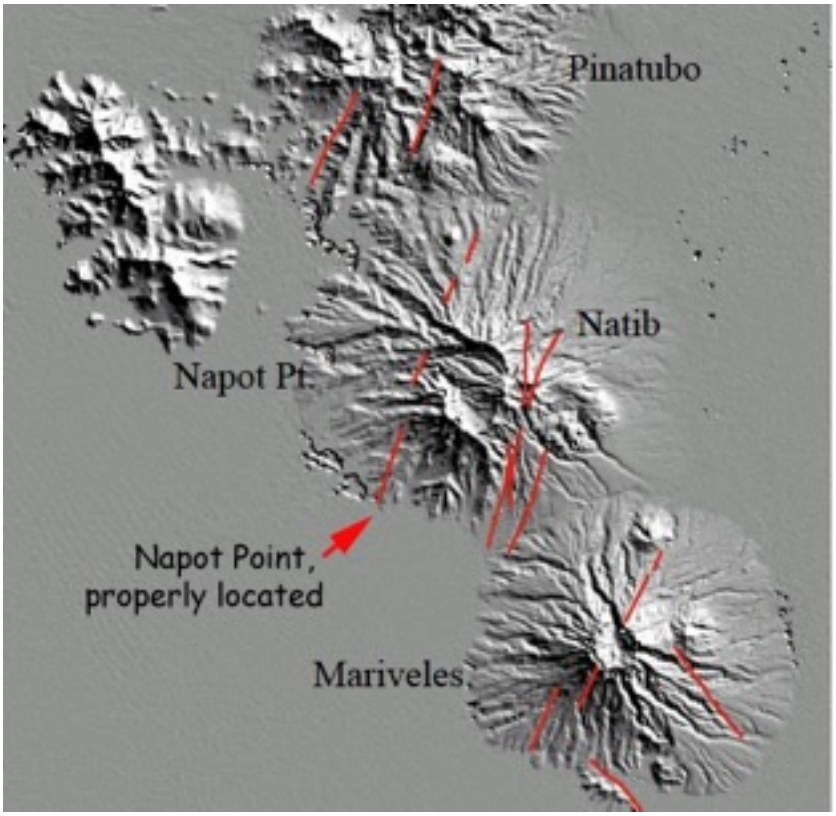

*FIGURE 2. Slide 34 of Arcilla's 2005 presentation[7], a satellite-derived terrain diagram provided by Dr. Mahar Lagmay. I have properly labeled the actual position of Napot Point, where the BNPP is situated. The lineation extending northeastward through Natib is essentially the Lubao Fault of Lagmay et al.[3]. The volcanic complex north of Mt. Natib is improperly labeled "*Pinatubo"*, which is actually 17 kilometers to the north.*

"The plant's location near Mt. Natib, he said, would not be a problem."

These statements were too momentous to take at face value; my wife and I verified them by listening to Orejas' tape of the interview.

Is it surprising, then, that an electrical-resistivity survey Arcilla conducted later confirmed his prejudgment by finding no evidence of a fault?

An electrical-resistivity survey cannot definitively rule out the presence of a fault, Dr. Arcilla's pronouncements to the contrary. The direct evidence presented by Hernandez and Santos in 1977[7] and Sonido in 1979[8] is much more meaningful. And as I will show, the work

of Lagmay and his group[3] document beyond doubt that active faulting occurs at the BNPP site.

At the House Appropriations Committee hearing on the BNPP in February 2009, Arcilla cited as evidence for the lack of faulting at Napot Point its absence in the MGB fault map. Unfortunately, Prof. Solita Monsod echoed that argument on nationwide GMA Ch 7.

That spurious reasoning means that the Subic Bay faults mapped in 2005 by Cabato et al.[6] and the Lubao Fault exhaustively mapped by Lagmay and his associates[3] also do not exist. Likewise, the Maraunot Fault cutting into the Pinatubo caldera published in 2007 by Lagmay et al., also the many Bicol faults mapped and published by Lagmay's Volcano-Tectonic Laboratory at UP-NIGS.

Dr. Arcilla made many other statements in a March 8, 2009 Philippine Inquirer interview[17] that cannot go unchallenged.

He said that an impending Natib eruption can be predicted in time to shut the plant down. That may be true, but it would not be possible to move the spent fuel rods to prevent catastrophe.

He acknowledged that Mt. Natib is potentially active, but said that the risk of an eruption during the 60 years that the BNPP will operate is very small. The IAEA is much more cautious.

When Napot Point was chosen to be the BNPP site in the 1970s, the IAEA had no safety standards for siting nuclear plants in volcanic terrain. It now does[18]. Quoting from those standards:

"Within a geographic region, volcanic activity can persist for longer time scales than associated with individual volcanoes. For example, many volcanic arcs exhibit recurring volcanic activity for longer than 10 Ma [million years], although individual volcanoes within the arc itself may remain active only for around 1 Ma. Because such distributed activity can persist for many millions of years, volcanic regions that have had activity during the past 10 [million years] should be considered to have at least the potential for future activity."

In that context, remember that the 1991 Pinatubo eruption, the world's worst of the last century, only 25 years ago. And Cabato et al. showed a pyroclastic flow from Mt. Natib no older than 18,000 years. Furthermore, there is evidence that Mt. Mariveles erupted as recently as 4,059 years ago[19].

Arcilla offered, as proof of Natib's harmlessness, that Phivolcs is not monitoring the volcano. Keep in mind that Pinatubo was also unmonitored until it became restive only three months before its 1991 eruption.

He defended the design of the BNPP by the safety records of "carbon copies" of the plant operating in Korea and Taiwan since the 1980s. Both countries have healthy "cultures

of safety" that we clearly lack, and Korea has neither volcanoes nor frequent seismicity. Furthermore, a 2009 news item details many problems at those Korean plants[20].

As proof of the BNPP invulnerability to earthquakes, he said that it was not damaged by the 1990 Luzon earthquake. This is absurd; the plant was not running! Think of the spent fuel pool, the vulnerable cooling-water intake, and high-tension cables of an operating plant.

He said the BNPP was mothballed as a reaction to the Chernobyl catastrophe in the Ukraine, but that US-designed nuclear power plants were far safer than their Russian counterparts. That may be true, but recall the details of shoddy BNPP construction described by *Fortune Magazine*[11].

The single most stubborn problem facing the nuclear power industry is the safe disposal of nuclear waste. According to the Journal *Nature*, the world's most respected scientific publication, no country in the world has yet solved this problem[21].

Arcilla cites the Waste Isolation Pilot Plant in underground salt deposits near Carlsbad, New Mexico as a model for nuclear-waste disposal. But WIPP accepts only transuranic waste -- clothing, equipment, tools, sludges, and soils contaminated during weapons manufacture. It cannot accept the high-level radioactive waste from nuclear power plants, which emits too much heat and includes too much liquid.

In the meantime, more than 77,000 tons of nuclear waste remain in spent-fuel pools and open-air casks at more than a hundred power plants in 32 of the United States. Since 1978, the United States has spent more than $90 billion in testing the proposed national waste depository at Yucca Mountain in Nevada. But the repository is considered unsafe because of its volcanic and tectonic histories -- much less recent than Natib's. In March 2009 the Obama administration declared that the Yucca mountain project is no longer as option[22]. No site has yet been identified to take its place.

And yet, Arcilla boasts, "Give me one island out of our 7,000 and I can find ways to store nuclear waste safely in the Philippines."

Pro-BNPP propaganda about faulting and earthquakes in general

The great attention Cojuangco and Arcilla have paid to the search for a fault under the BNPP dangerously misleads the public about faults and earthquakes. Even if there were no fault at the BNPP site, the plant could experience serious damage from an earthquake many kilometers away.

For example, Manileños need to know that a major earthquake on the West Marikina Valley fault would probably be most damaging not along the fault zone itself, but in places built on natural bay fill and artificially reclaimed land including Tondo and the Asia Mall[23]. The earthquake damage directly along the trace of a fault is usually minor compared to the total damage in the affected area. Keep in mind that in 1968, Manila was hard hit by a magnitude 7.3 earthquake in Casiguran, Quezon**,** 225 km away (Su 1969, Osome et al. 1969). Many structures that were built on river deposits near the mouth of the Pasig River in Manila were destroyed. The six-story Ruby Tower in Binondo collapsed from amplified ground shaking, liquefaction, or both, killing 260 people. Furthermore, the great 1990 earthquake in

Nueva Ecija greatly damaged Baguio and Dagupan, cities 100 kilometers away from the epicenter.

Any college student in an introductory geology course knows that earthquakes usually occur in a fault zone along new breaks called "rogue faults". The 1990 magnitude 7.8 earthquake centered beneath Rizal, Nueva Ecija created entirely new breaks in the ground. So the lack of a fault trace at any earthquake-prone locality does not mean that an earthquake cannot occur there.

This obsession with faults directly under the BNPP, and frequent statements by Cojuangco and his allies that Japan is volcanic and earthquake-prone and yet very much powered by nuclear reactors, ignored the lessons of the July 6, 2007 Niigataken Chuetsu-oki earthquake. Apparently, so did the Japanese authorities before the 2011 Fukushima disaster.

The July 2007 Kashiwazaki-Kariwa Nuclear Power Station (K-KPS) disaster in Japan

By now, all Filipinos know about the Fukushima disaster. Few, however, are familiar with the K-KPS disaster that occurred five years before (Figure 4). It was triggered by an earthquake of only moderate (Mw 6.6) magnitude that occurred 17 km below the surface, 23 km offshore from the K-KPS)[24,25,26]. This nuclear facility, the largest in the world with a 60.5 trillion watt-hour peak annual output – more than 1,200 times the total Philippine consumption – has been shut down ever since.

The earthquake was generated by a "reverse" or "thrust" fault. The motion occurred when a block of offshore crust was suddenly forced underneath the landward crust on which the K-KNPS sits, pushing it upwards. Such motion against the pull of gravity causes more damage than the sideways motions caused by an earthquake of equivalent magnitude along faults like the Philippine Fault.

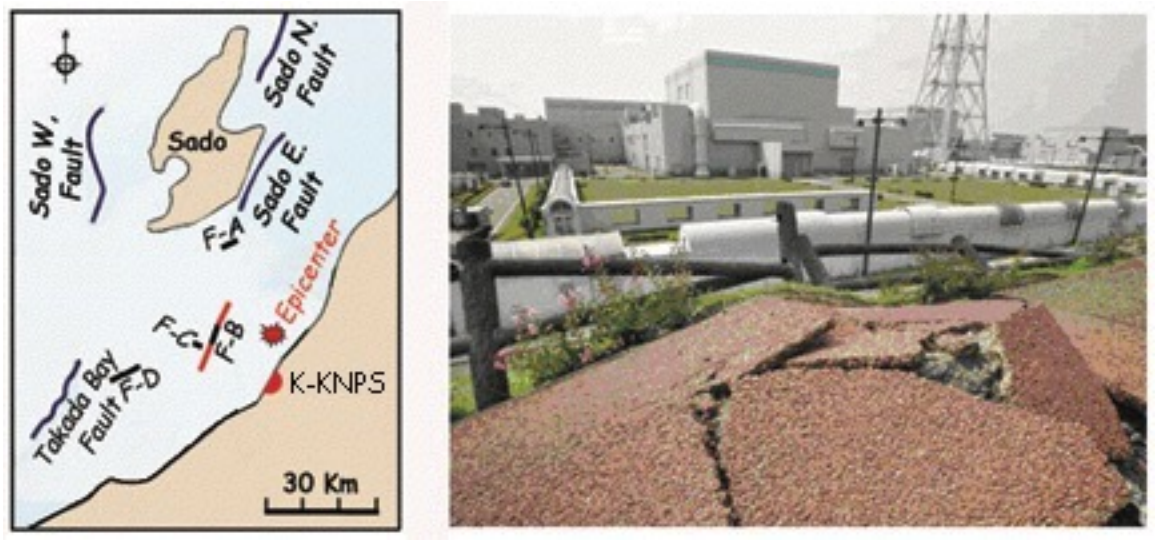

FIGURE 4. The Kashiwazaki-Kariwa Nuclear Power Station and the 16 July 2007 magnitude 6.8 Niigataken Chuetsu-oki earthquake. Left, a pre-earthquake geological

offshore survey recognized four short earthquake traces numbered F-A to F-D. Fault F-B, 7 kilometers long, was mistakenly adjudged to be inactive. After the earthquake, it was more than three times longer (red lines). The earthquake occurred on a plane dipping southeastward from F-B underneath the K-KNPS (modified from Takekuro, 2008[26]). Right, ground rupture at the K-KNPS. From Cyranoski, 2007[24] .

Major earthquakes generated along the Manila Trench are also reverse faults. If one occurred there offshore from BNPP, the motion would also be upwards. Direct evidence of fault displacement could be entirely missing at the BNPP itself, because it would occur many kilometers below the surface. The right panel of Figure 4 shows that the Niigataken Chuetsu-oki earthquake did cause ground rupture at the K-KNPS, but this was caused not directly by fault displacement, but by earthquake waves propagating through the site. This picture demonstrates that nobody can guarantee that the BNPP is immune from ground rupture from earthquakes, as Cojuangco claims Phivolcs has assured him.

The Japanese, as industrially advanced as they are, do make huge mistakes, such as building the K-KNPS in the first place. Quoting the IAEA[25], "The … levels of seismic ground motion estimated in the design process were very significantly exceeded by the event... the newly calculated seismic hazard at the site is much higher than both the July 2007 event and the original design earthquake level".

K-KNPS has had serious problems before[22]. After deliberately falsified data were discovered in September 2002, all seven reactors were shut down. Units 1, 2, and 3 generated no electricity during the entire 2003 fiscal year, so the station produced only a third of its capacity.

So much for Cojuangco's frequent claim that nuclear energy is reliable and safe. And so much also for the Filipino infatuation with Japanese disaster planning and prevention technology.

Recent earthquakes near Natib Volcano

FIGURE 5. Earthquakes of moderate magnitude in the Mt. Natib and BNPP vicinity from 1951-2016. From USGS National Earthquake Information Center[26].

Many earthquakes have happened in the vicinity of BNPP (Fig. 5). Many are situated along the Lubao lineament. One of them occurred directly under Napot Point, like the one mentioned by Hernandez and Santos in 1977[7].

The Lubao Fault

In 1997, Prof. Fernando Siringan, his students and I began to study land subsidence in coastal Bataan, Pampanga, Bulacan and Kamanava. Very early, we noticed a sharp lineament in Lubao, Pampanga that trends southwest to Mt. Natib, where it abruptly disappears (Figure 6). Many of the earthquake epicenters in Figure 5 plot along the lineament which, if extended farther, trends to Napot Point. Mahar Lagmay and his associates[3] have used sophisticated satellite data to show that the lineament is an active fault, and that its northwest side is moving slowly southward relative to the southeast side. They have also studied the geology of Natib Volcano in detail on the ground.

FIGURE 6. Landsat image of the Bataan Peninsula and the Lubao Fault. Many of the earthquakes in Figure 5 plot along the fault. The trend extends offshore, manifested in the submarine topography. From Lagmay et al., 2012[3].

Figure 7. Evidence of faulting at the BNPP site. (a) 25 m-high outcrop of faulted lahar deposits. (b and c) Close-up photographs of rock masses sheared and deformed by faulting. (d) Scarp extending in the NNE direction from the faulted outcrop into the BNPP fenced perimeter. The BNPP facility is at the far right. From Lagmay et al., 2012[3].

At Napot Point, the rocks are deposits of pyroclastic flows and lahars, testimony to the susceptibility of the BNPP to those dangerous volcanic hazards. Equally ominous, these rocks are severely deformed by faulting (Figure 7).

Concluding Statement: A Retrospective

Congressman Cojuangco claims that the Philippines owes its status as a poorly industrialized impoverished country to its lack of electricity, and that the operation of the BNPP would go a long way toward correcting that status.

I prefer to attribute our industrial and technological backwardness to a national lack of respect for science and scientific fact, so graphically illustrated by the entire sorry history of the BNPP and the current efforts to revive it.

Since beginning to study lahars at Mayon Volcano in the 1980s, my data, if judged "inconvenient" by various governmental entities, have been trivialized, distorted or disregarded, and the people have suffered.

While conducting our pioneering lahar studies at Mayon, young Phivolcs geologists and I were continually frustrated as we watched how government engineers ignored or misused our knowledge as they built flimsy, graft-ridden "lahar containment" dikes. When a small lahar damaged one, it would be repaired to the same flimsiness. Volume for volume,

laharic debris flows are an order of magnitude more powerful than stormfloods. But our knowledge never made it to the engineer's drafting table or to the structure in the field.

That disregard or misuse of science finally bore its ill fruit two decades after we began studying Mayon lahars. In November 2006, lahars spawned on Mayon by Typhoon Reming "…overtopped river bends, breaching six dikes through which they created new paths, buried downstream communities in thick, widespread deposits, and caused most of the 1,266 fatalities," as described in the international scientific literature in a paper[29] first-authored by Engielle Paguican, another bright young Filipina scientist.

To this day, no one is accountable for these deaths. Apologists for the failed dikes say that nothing can withstand a supertyphoon. But proper hazard-containment engineering builds for the worst case. To do otherwise merely endangers people by giving them false assurance of their safety.

The engineering sins and graft at Mayon were repeated on a much larger scale at Pinatubo. In 1995, a new dike was built along the Gugu River between San Fernando and Bacolor in Pampanga. People in its shadow believed that the dike protected them.

But on 1 November 1995, the worst disaster at Pinatubo happened when lahars of Typhoon Mameng overwhelmed the Gugu dike. Huge lahars, enlarged by eroding and absorbing a one-kilometer stretch of the dike, descended upon Cabalantian, a Pampanga barangay of some ten thousand souls. To this day, no one has been held accountable for the many deaths in Cabalantian.

More recently, Dr. Fernando Siringan of the Marine Science Institute and I continue to battle the life-threatening Kamanava flood-control project of the Department of Public Works and Highways. That 5 billion peso project both ignores and trivializes our data, confirmed by NAMRIA, that show Kamanava unevenly sinking several centimeters every year. The project also blatantly minimizes the heights of storm waves and surges that would obliterate the dikes and river walls during a major typhoon.

At present, 102 near-shore reclamation projects covering 38, 272 hectares in Luzon, Visayas and Mindanao have been proposed by the government and private interests[23]. Of these, 38 projects with an aggregate area of 26,234 hectares are intended to reclaim virtually the entire near-shore zone of Manila Bay The ongoing rush to execute several of these projects is alarming in how little its proponents seem to understand the littoral environment, their seeming indifference to the hazards it poses, and how they deliberately ignore Filipino scientists and their expertise.

Truly, a little knowledge is a dangerous thing, in a country where the desires of a dictator with no scientific training, followed decades later by a similarly uninformed

legislator and his supporters, outweigh technical and scientific fact and endanger the populace.

Sources

The pro-BNPP propagandists make extravagant claims that are mostly undocumented. I have taken pains to provide references from reputable sources, and wherever possible have provided internet links for easy access.

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