Ethical Considerations in Determining the Societal Investment in Warning Future Generations about Latent Long-term Risks from Radioactive Waste Disposal Facilities -- 17058

Abraham Van Luik*, Russell Patterson*, Thomas Klein**, Robert Watson**
*Department of Energy, Carlsbad Field Office, 1441 National Parks Highway, Carlsbad, New Mexico 88220
russ.patterson@cbfo.doe.gov

**AECOM, 400-2 Cascades, Carlsbad, New Mexico 88220
Tom.Klein@wipp.ws
Rob.Watson@wipp.ws

ABSTRACT

Writers and philosophers have long romanticized and pondered the great challenge of communicating with future generations. The only way that man can travel through time. Never has this notion been more studied and debated than in the nuclear waste disposal arena. Regulatory requirements in the United States and internationally, require that there be some form of notification of future generations in place once a deep geologic nuclear waste repository has been closed. It is considered a generational responsibility. Since the difficulty of this task is so daunting, it has been assumed that the monetary cost to accomplish this millennia-spanning message-in-a-bottle must also be extreme. This paper will discuss both the ethical and equitable implications across generations, as they pertain to the reality of future inadvertent intrusion scenarios and the associated cost of communicating through time to prevent them.

INTRODUCTION

The general press has written about the challenge facing radioactive waste management organizations once their deep geological disposal systems have been filled and sealed: warning future generations about the risk underground. As one front-page Wall Street Journal article had it [1]:

> *Early Warning: How To Alert Earthlings of Yucca Mountain . . .Much Thought Is Devoted to Telling Folks in 12,003 About Our Nuclear Waste*

The article suggests that nuclear waste management organizations are faced with needing “to devise warnings and safety barriers that will long outlast today’s most ancient relics of civilization.” Those ancient relics, the article points out, include “The world’s oldest stone monument—the Step Pyramid in Egypt—[which] is just 4,000 years-old.” The article suggests this to be a monumental task. In other words, it is likely to be a huge investment. The article cites a person who arranged for an exhibit of possible marker ideas who feels that, "Whatever marker is chosen needs to be a monument to our mistakes, not our achievements."

This value-laden attitude is also reflected in the recommended language for a repository marker for the Waste Isolation Pilot Plant (WIPP) in New Mexico by a group of experts commissioned to make recommendations for marking the WIPP repository. They suggested starting the warning message with this statement [2]:

> ***This place is not a place of honor.***
> ***No highly esteemed deed is commemorated here.***
> ***Nothing valued is here.***
> ***This place is a message and part of a system of messages.***
> ***Pay attention to it!***
> ***Sending this message was important to us.***
> ***We considered ourselves to be a powerful culture.***

Although current thought is to not transmit value-laden messages, the overall set of recommendations produced by this expert group has been given serious consideration in the current WIPP marker design. The experts recommended that "*Other nuclear waste disposal sites must be marked in a similar manner within the U.S. and preferably world-wide."* The Department of Energy and the Management and Operating Contractor overseeing and managing the WIPP repository agree, hence their substantive involvement in the Paris-based Organisation for Economic Co-operation and Development's Nuclear Energy Agency initiative on Preservation of Records, Knowledge and Memory (RK&M) across Generations. (https://www.oecd-nea.org/rwm/rkm/).

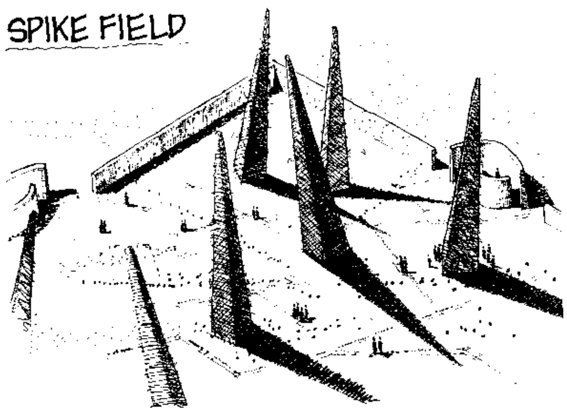
When the expert group made this recommendation in 1992, they stated what would have been obvious even if left unstated:

> **"We obviously recommend that a very large investment be made in the overall framework of this system, in the marking of the entire site, and in a communication mode** (emphasis added) that is non-linguistic, not rooted in any particular culture, and thus not affected by the expected certain transformation of cultures."

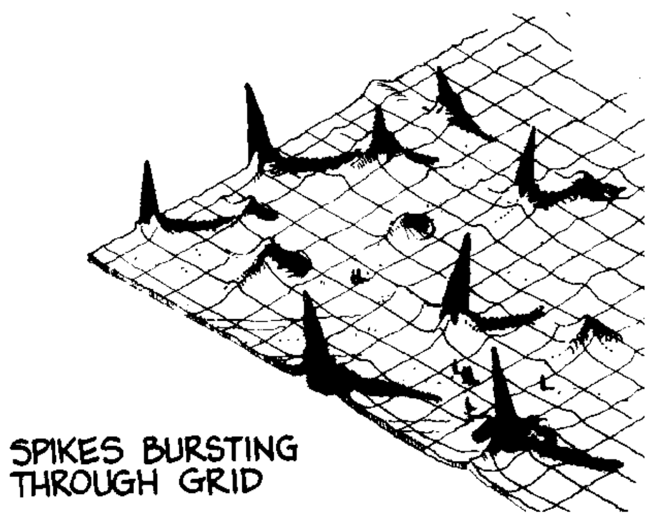
What constitutes a "very large investment"? The recommended WIPP site marker systems are elaborate and may be impracticable. Their ideas were all to make the place of the repository "forbidding and uncomfortable."

In their report, they provide drawings of the marker concepts, all with forbidding titles such as (http://www.wipp.energy.gov/picsprog/articles/wipp%20exhibit%20message%20to%2012,000%20a_d.htm):

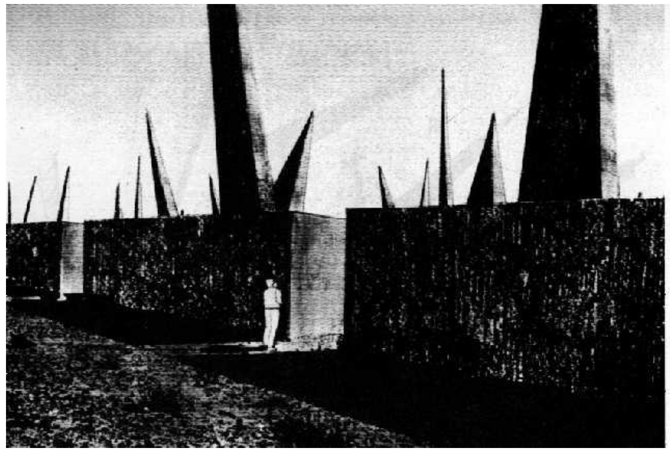
Landscape of Thorns



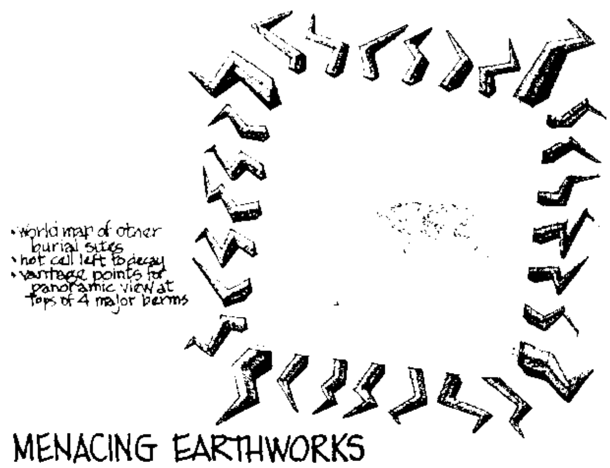
Spike Field



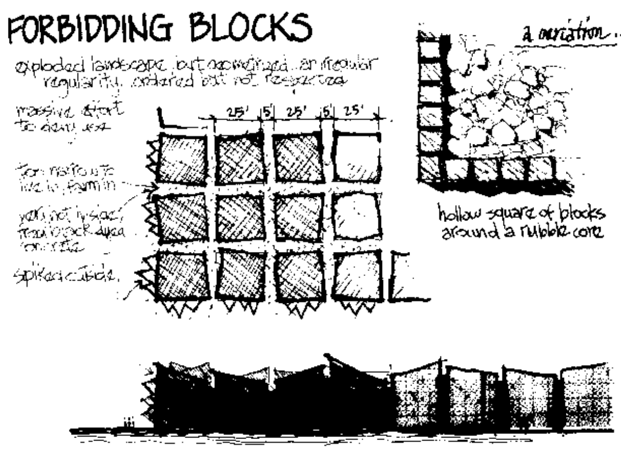
Spikes Bursting Through Grid



Leaning Stone Spikes



Menacing Earthworks



Forbidding Blocks

The experts explained that:

> "Some designs use images of dangerous emanations and wounding of the body. Some are images of shunned land...land that is poisoned, destroyed, parched, uninhabitable, and unusable. Some combine these images. All designs entirely cover or define at least the interment area ..."

The currently proposed WIPP marker design is not as elaborate as these experts suggested, and seeking to convey information rather than values to the future. Yet it may still be too much of an investment for current generations to be burdened with in view of the very real challenges to health and well-being faced in the real world of today and the insignificant risk posed by a properly filled, closed, and sealed repository.

Taking away resources from a population that needs them, to protect an unknowable but certainly very small number of far future persons from a hypothetical and insignificant risk of exposure is an ethical issue. It raises questions of fairness and justice.

THE ETHICS OF REPOSITORY MARKER SYSTEMS

The online BusinessDictionary.com (http://www.businessdictionary.com/) defines "ethical" in part to mean [3]:

> "Equitable, fair, and just dealing with people that, although pragmatically flexible according to the situation and times, conforms to self-imposed high standards of public conduct."

The same source defines "equitable" to mean a:

> "Remedy or solution that is ethically or legally just and reasonable under the circumstances, but may or may not be wholly satisfactory to any or all the involved parties."

If we look at the proposed cost of warning future generations about a likely to be minor, small exposed population risk, we might see it as an issue of making an "ethical investment," which the same source defines as an:

> "Investment philosophy which attempts to balance the regard for morality of a firm's activities and regard for return on investment. Ethical investors seek to invest (usually through mutual funds or unit trusts) in firms which make a positive contribution to the quality of environment and quality of life."

This last definition may seem a bit off the topic at first, but if we recognize that nuclear utilities make a positive contribution to a nation's quality of life by providing clean (in terms of carbon emissions) and generally affordable power, that isotope manufacturers enhance the quality of available medical care in a nation, and that national defense programs are seen –at least within those nations—as preventing war, then the definition fits. Markers of geologic disposal facilities are marking the disposal of materials that have made a positive contribution to the lives lived in their nations, and an investment in those markers can be seen a continuation of that ethical investment. Holtorf and Högberg stated in their recent paper entitled "Nuclear Waste as Cultural Heritage of the Future" [4]:

"*If nuclear waste was seen as another form of cultural heritage it could become a lot easier to persuade contemporary audiences that it might in the future be seen in a very different light than today so that even more realistic plans for its storage and disposal could be made*."

Of course all aspects of the use of nuclear energy have strong detractors, as already seen in the introduction, but we are not engaging in that argument here. We are engaged in this repository marker business with a bona-fide claim to be acting ethically in so doing. We believe that overall the producers of radioactive waste have made a positive contribution to the quality of life at least within their nations, and we believe we are continuing this ethically positive activity by responsibly and safely discarding of radioactive wastes and marking waste disposal systems properly.

Properly means ethically, means equitably, means just and reasonable. Therefore we want to look closely at the experts' idea that: "**a very large investment be made**"—we feel no guilt at being in this waste disposal business and we feel that what we are doing is NOT pushing a meaningful risk away from ourselves and into the far distant future. To be more direct, no matter how one feels about the creation of nuclear weapons, this place is where we remove a real, existing risk from the biosphere, out of normal human reach, and turn it into a potential risk that is likely to never be fully realized. For intermediate and high level wastes, deep geologic repositories are the responsible thing that these current generations can and should do for the sake of future generations who may perceive these locations differently than we do today. It is the honorable thing to do, and hence these are honorable places.

But ethics requires equitably matching the investment to the benefit. The investment in markers and other passive "controls" ought to be balanced by the risk being averted. So just what is that risk?

WHAT IS THE LONG-TERM RISK FROM A SEALED DEEP GEOLOGIC REPOSITORY?

REGULATORY PERSPECTIVES

Regulators around the world in countries with nuclear waste management operations are struggling, and have struggled, with this question. The answers they have come up with are diverse. The reason that regulators write regulations that --most often-- prescribe performance measures and goals for the long-term performance of a repository is to assure long-term safety.

Typically one standard is set for undisturbed performance, another may be set for disturbed performance involving unanticipated, low probability events and processes. Yet another may be set for human intrusion events, sometimes looking at the potential acute consequence for the unwitting driller and always looking at the chronic exposure consequence for the local resident that may be affected by what the drilling occurrence brings into the biosphere and its aquifers from far below.

USA

The regulations for WIPP, 40 CFR 191[5] and 40 CFR 194[6], are unique in that they set one standard (Table 1), and several probabilistically defined intrusion events occurring in every 10,000-year performance calculation (Figure 1). These events are statistically added into the overall cumulative distribution of release magnitude and probability, and matched against the allowable release fraction defined by the Environmental Protection Agency in 40 CFR 191.13. Each 5 years the results of performance assessments are assembled into complementary cumulative distribution functions (CCDFs) that represent the probability of exceeding various levels of cumulative release caused by all significant processes and events and provided to the regulator in a compliance recertification application (CRA).

TABLE 1—RELEASE LIMITS FOR CONTAINMENT REQUIREMENTS*

[Cumulative releases to the accessible environment for 10,000 years after disposal]

Radionuclide	Release limit per 1,000 MTHM or other unit of waste (see notes) (curies)
Americium-241 or -243	100
Carbon-14	100
Cesium-135 or -137	1,000
Iodine-129	100
Neptunium-237	100
Plutonium-238, -239, -240, or -242	100

Radium-226	100
Strontium-90	1,000
Technetium-99	10,000
Thorium-230 or -232	10
Tin-126	1,000
Uranium-233, -234, -235, -236, or -238	100
Any other alpha-emitting radionuclide with a half-life greater than 20 years	100
Any other radionuclide with a half-life greater than 20 years that does not emit alpha particles	1,000

*Taken from 40 CFR 191, Appendix A to Part 191 – Table for Subpart B

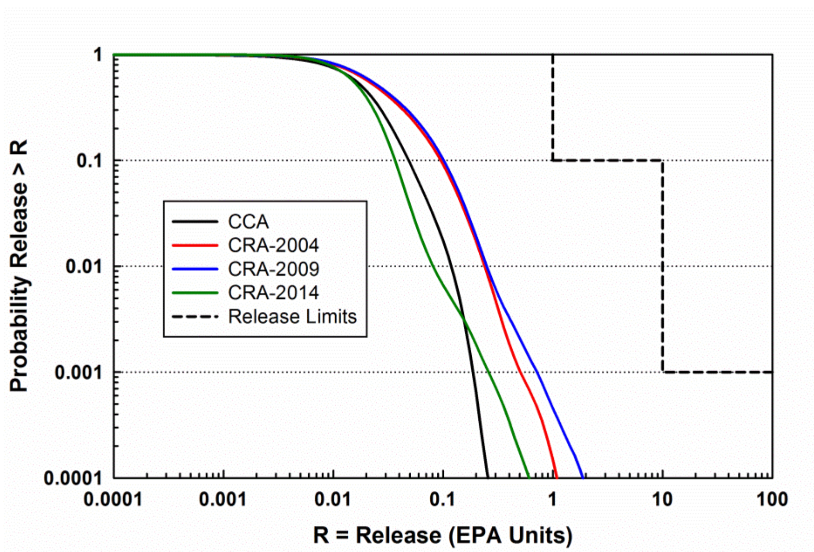


Figure 1, CCDF curve example.

There is no release from the undisturbed case, or from the less likely non-human intrusion cases, so the only contributor to the long-term release calculation is human intrusion. Even with an average of seven such intrusions in 10,000 years, that release allowance is not violated.

For the WIPP repository, the primary human intrusion scenario involves drilling for natural resources. The mandated formula for calculating the drilling frequency is not sustainable for ten-thousand years. Nothing is sustainable for ten-thousand years; least of all an ever-increasing extraction rate for finite natural resources such as oil and gas. Therefore, the drilling frequency is itself extremely conservative. The treatment of the details of drill hole waste encounters, brine encounters, solubility and concentrations of actinides in intruding brines, and the translation from upward moving contaminants in an active drill chain into the more permeable horizontal zones below the ground surface are all conservatively assumed, populated with data, and calculated. Yet still the repository is judged safe by the EPA standard defined in CFR 191 and CFR 194. Three times now, in the Compliance Certification Application decision [7], the Compliance Recertification Applications from 2004[8] and 2009[9], the EPA has agreed that the repository, in spite of numerous human intrusion scenarios, remains safe. The EPA did not allow any credit for warning the future beyond 100 years, even though it is mandated in the regulation that warnings be posted that are as long lasting as practicable. The bottom line is that a TRU waste repository in deep bedded salt, even with natural resources below it and expected human intrusions in the future, like WIPP; poses a very low risk to the future humans and the environment.

But the foregoing is a very specific rock type, waste type, and regulation-prescribed human intrusion scenario case. What about repositories in other types of host rocks? Some countries are characterizing clay (argillaceous) as a host rock, several are to use granite-like (crystalline) intrusive rock, and in the US there was a proposal to use an unsaturated volcanic tuff mountain as a repository host (Yucca Mountain).

Although regulatory approaches vary in each country, the 1995 opinion of the US National Academy of Sciences regarding the evaluation of human intrusion scenarios for the proposed Yucca Mountain repository has had considerable influence. Their National Research Council members addressing this issue stated on pages 108 and 109 of the Technical Basis for Yucca Mountain Standards that [10] (http://www.nap.edu/read/4943/chapter/6#108):

> . . . the benefits of passive markers outweigh their disadvantages, at least in the near term.
>
> . . . because it is not technically feasible to assess the probability of human intrusion into a repository over the long term, we do not believe that it is scientifically justified to incorporate alternative scenarios of human intrusion into a fully risk-based compliance assessment . . .
>
> . . .it is possible to carry out calculations for the consequences for particular types of intrusion events . . .

> . . . calculations of this type might be informative in the sense that they can provide useful insight into the degree to which the ability of a repository to protect public health would be degraded by an intrusion.
>
> . . . Because the assumed intrusion scenario is arbitrary and the probability of its occurrence cannot be assessed, the result of the analysis should not be integrated into an assessment of repository performance based on risk, but rather should be considered separately. The purpose of this consequence analysis is to evaluate the resilience of the repository to intrusion.

The world advisory standard issued by the International Atomic Energy Agency, SSR-5 Specific Safety Requirements [11] (http://www-pub.iaea.org/mtcd/publications/pdf/pub1449_web.pdf) provides an exposure level below which there is no concern for persons living near the repository site:

> 2.15. . . .
>
> (c) In relation to the effects of inadvertent human intrusion after closure, if such intrusion is expected to lead to an annual dose of less than 1 mSv to those living around the site, then efforts to reduce the probability of intrusion or to limit its consequences are not warranted. . . .

The next paragraph gives an important caution about basing judgments on the outcomes of very long term calculations (such as assumption-based far-future human intrusion scenario calculations):

> 2.16. It is recognized that radiation doses to people in the future can only be estimated and that uncertainties associated with these estimates will increase for periods farther into the future. Caution needs to be exercised in applying criteria for periods far into the future. Beyond such timescales, the uncertainties associated with dose estimates become so large that the criteria might no longer serve as a reasonable basis for decision making.

The NAS report from 1995 was echoed by more recent advice from the International Commission on Radiological Protection (ICRP 2013), which is basically to evaluate human intrusion doses or risks but not hold them to the standard assigned for the long term safety of the un-intruded repository [12].

IAEA

The IAEA's BIOPROTA Project [IAEA BIOPROTA 2013] produced an interim report [13] that sought to answer many of the questions repository programs have about human intrusion. The report:

> . . . 1) examined the technical aspects of why and how deep geological intrusion might occur; 2) considered how and to what degree radiation exposure would arise to the people involved in such intrusion; 3) identified

the processes which constrain the uncertainties; and hence 4) developed and documented an approach for evaluation of human intruder doses which addresses the criteria adopted by the IAEA and takes account of other international guidance and human intrusion assessment experience.

Of particular interest here is "how and to what degree radiation exposure would arise to the people involved in such intrusion." Calculations were performed that were consistent with international recommendations for six different drilling techniques, two types of materials being brought to the surface (soft, meaning clay and bentonite; and hard, meaning crystalline rock, concrete, and metal canisters) and two types of workers (driller and geologist). The results are shown for doses normalized to 1 Bq/g of a given radionuclide in the material brought up to the surface by drilling. A reality case is then presented for High Level Waste (HLW) and Low Level Waste (LLW) suggesting that for HLW the normalized results ought to be multiplied by anywhere from 10^5 to 10^7. This suggests that considerable doses may be possible at about 10-15 Sv/a for a driller or geologist encountering and handling contaminated core. Being possible does not make a statement of risk, however. No effort was made to estimate the likelihood of such exposures.

UK

The UK Nuclear Decommissioning Authority [NDA 2010] [14] evaluated a generic spent nuclear fuel repository in hard rock in terms of dose to the driller and estimated 50 Sv doses as possible (considered lethal) if the intrusion occurred within the first 1,000 years. To put such a result into perspective, NDA estimated a mean drilling frequency of 10^{-10} holes drilled per m^2 per year for hard rock areas in the UK. For a hypothetical 1 km^2 repository footprint, 10^6 m^2, that means 0.1 such instances over 10^3 years. A result like this puts the dose in perspective, perhaps one fatality in 10^4 years? But much of the set of assumptions regarding the waste form, the likelihood of a direct hit of the most radioactive material, the likelihood of a meter long core, the diameter of the core, etc., all play a role in determining the significance of the exposure should it occur.

It is assumed that drilling mud with contaminants remains on site after the drilling has stopped, the borehole is left open breaching repository barriers permanently, and a local resident farms on soil contaminated by that activity and may use contaminated water from around the breached repository. None of these things would occur under current rules and practices. If current standards are in place and it is acknowledged that deep drillers tend to be as sophisticated as their investment demands, of course there would then be a competent sealing of the borehole and cleanup of the site. Much that is assumed to allow calculations of human intrusion scenario exposure risks is unrealistic. Hence the international (and national in the US) recommendations: do not use human intrusion scenario for more than a qualitative assessment of repository resiliency in the case of an intrusion.

So where does all that uncertainty leave us in making an equitable and ethical investment decision on preventing human intrusion?

Conclusion

Is it ethical to use the present generations' monetary and physical resources to attempt to save a future human intruder into a waste burial system from potential harm? While there is an ethical duty and a regulatory requirement to do what is practicable in terms of equitably warning future generations, how much time and resources should this generation be expected to expend on this endeavor?

These are ethical and equitable questions that must be answered by expertise including the technical and addressed by society itself. The authors of this paper have no answers for these questions, but know the recommendation made by the expert panel in the US in the 1990s to mark the WIPP repository "**a very large investment be made**" is not realistic, ethical, or equitable.

Regulators and scientists from around the world with nuclear waste programs have independently identified extremely minimal exposures to future generations by a properly designed and constructed nuclear waste geologic repository. Calculated and modeled exposures to future generations involving the primary exposure activity of drilling for natural resources through a nuclear waste repository resulted, even when extreme conservatism is calculated, in extremely minimal exposures to very minimal future generation populations. Development of a marker system, by today's generation, should be financially ethical and equitable to the calculated potential impacts to future generations. To determine any type of an accepted cost expended as it relates to benefit received by future generations, expertise involving more than just regulators and nuclear modeling experts needs to be involved.

This is the sort of calculation that needs expertise beyond just the technical. But the recommendation made by the expert panel in the US in the 1990s to mark the WIPP repository is not realistic, ethical, or equitable.

References:

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[3] Ethical. (n.d.) In Business Dictionary online. http://www.businessdictionary.com/

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[13] IAEA BIOPROTA 2013, *Human Intruder Dose Assessment for Deep Geological Disposal*, Working Report 2013-23, Graham M. Smith, Jorge Molinero, Anne Delos, Alba Valls, Adriana Conesa, Karen Smith and Thomas Hjerpe [http://www.posiva.fi/files/3301/WR_2013-23.pdf]

[14] Geological Disposal: Generic Operational Safety Assessment, Vol 1-4. December 2010. Nuclear Decommissioning Authority. NDA Report No. NDA/RWMD/054.