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Options for Elimination of Technical Uncertainties from the Groundwater Travel Time Rule

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Prepared by

R. T. Green
B. Sagar

Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

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1 INTRODUCTION

With a view of streamlining the licensing process for the first high-level nuclear waste repository, the Nuclear Regulatory Commission (NRC) is engaged in resolving various uncertainties that may be lodged in its regulations incorporated in 10 CFR Part 60. This report focuses on one particular Regulatory Requirement (RR) from out of 10 CFR Part 60--that related to the pre-waste-emplacement groundwater travel time (GWTT). After briefly describing the uncertainties in the GWTT RR, various options for resolving the uncertainties are outlined. To select one or more of these options for implementation, they will be evaluated against a set of subjective/objective criteria that are currently under review.

Systematic Regulatory Analysis of 10 CFR Part 60 has identified three potential technical uncertainties in the regulatory requirement encoded in 10 CFR 60.113(a)(2) that pertains to groundwater travel time. In the following, this RR will also be sometimes referred to as the GWTT rule. It is important to recall that technical uncertainties represent lack of clarity regarding how compliance with the regulatory requirement is to be demonstrated by the Department of Energy (DOE) or determined by NRC. In the particular case of the GWTT RR, compliance demonstration is unclear because of the use of terms 'fastest path of likely radionuclide travel' and 'disturbed zone' which are not uniquely definable in natural heterogeneous and fractured geologic media whether saturated or unsaturated. The third technical uncertainty stems from the fact that the current language of the rule leaves it incomplete because no volume (or mass) is associated explicitly with the GWTT.[1] At present, the natural interpretation of GWTT appears to be the earliest arrival time of a tagged macroscopic[2] particle as is evident from the many published analyses (e.g., Kaplan, 1992).

Resolution of uncertainties in the various RR's, to the extent possible, is an important step towards streamlining NRC's licensing process. To resolve the technical uncertainties in the GWTT RR, a systemic analysis of the rule was undertaken. This analysis encompassed a review of literature regarding the history of the rule making as well as previous commentaries on the rule. A task group of staff from the Center for Nuclear Waste Regulatory Analyses (CNWRA) and the NRC Division of High Level Waste Management (DHLW) studied the literature to clearly identify the intent of this RR. Specific documentation that assists in defining the intent of the GWTT performance measure of the geologic setting has been taken from NUREG-0804.

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[1] For this discussion, a rule is complete if all essential parts of a rule are explicit viz each rule should specify a compliance distance, a time of compliance, and the material amount that must be complied with.

[2] A macroscopic particle represents a scale at which bulk motion of fluid can be described. In porous media flow, its size is many times the size of the average pore yet it is small enough that its mass can be assumed to be infinitesimal. More precisely, for porous media flow, the macroscopic dimension is the minimum length scale at which Darcy's law applies.

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- "Following release of radioactive materials from the engineered barrier system, the geologic setting alone must provide whatever additional isolation is needed to keep radioactive materials entering the accessible environment to acceptable levels" (page 472).

- "The objective is for the geologic setting, through long groundwater travel times and geochemical retardation, to delay the arrival time of radionuclides at the accessible environment for many thousand years" (page 472).

- "In a complementary manner, the geologic setting will compensate for uncertainties in the performance of the engineered barrier system. A minimum groundwater travel time can provide quantifiable compensation for premature failure of or excessive early releases from the waste package and underground facility" (page 491).

Based on the above written record and from other discussions with technical personnel with first hand knowledge about the formulation of this RR, it was concluded that the intent of the GWTT RR can be expressed as:

(1) set a measure of the geologic setting to compensate for premature failure (during the containment period of 300 to 1,000 years) of or excessive early releases from the waste package and underground facility; and/or

(2) set a measure of the long-term performance (of the order of 10,000 years) of the site in terms of delaying the arrival of radionuclides at the accessible environment.

It is to be noted that the second objective listed above encompasses within itself the first because if a site is "good" for the long-term then it is also "good" for the short-term. In the following, some options are stated for the first measure to cover the situation where only the first objective is taken to be the sole intent.

It has became apparent that several attributes were associated with the performance measure of the geologic setting. The GWTT rule and the other subsystem performance requirements were supposed to be simpler to implement and evaluate than the requirements in the EPA standard (40 CFR Part 191). At the time the GWTT RR was formulated, there was some expectation that it may be possible to experimentally determine (rather than calculate) the subsystem performance measures at a proposed site. It appears that unsaturated sites were not of great concern at the time the GWTT rule was developed. As a consequence of having a rule that was ostensibly developed for the saturated zone, it is not clear whether water vapor (or gas) migration is included in the GWTT RR. We have postulated some options that apply to gas flow. Currently, compliance with the subsystem performance requirements will most likely be demonstrated using mathematical models as is also the case for demonstrating compliance with the more complex EPA standard. However, some options in this document contain performance measures that can be directly measured. It is expected that the simpler the performance measure, the more reliable it will be but at the same time it will probably not be fully representative of all aspects of site

performance. This tradeoff will be discussed in greater detail during selection of the preferred option.

A number of options may be available for resolving the technical uncertainties in the GWTT RR discussed above. These options range from removing altogether the GWTT requirement from the regulations at one extreme, to taking no action to resolve the uncertainties at the other extreme. In this document, an effort is made to develop a comprehensive set of these options which then can be evaluated with respect to well defined criteria with the objective of choosing an option that best meets the intent and that is scientifically defensible. For completeness, even those options that obviously do not resolve the uncertainties are included in the option set.

For ease of discussion, various options have been categorized into hierarchial groups as shown in Figure 1. Each option class follows from a presumed action that the NRC may decide to take for resolving the identified technical uncertainties. The highest-order option class in this hierarchy stems from whether to maintain the GWTT requirement as it is currently stated or to change the language of the rule. Changing the language of the GWTT requirement may necessitate a rulemaking.

If one chooses to retain the GWTT RR in its current form, the next lower level of action is to either provide guidance to the licensee concerning this RR or to take no action and let the uncertainties persist. On the other hand, if one chooses to not retain the RR in its present form then there is an option of either not providing any performance measure for the geologic setting or specifying an alternative performance measure. Of these four potential second-level choices, only the last choice viz, changing the GWTT rule, has significant, potential, lower-level choices. The full hierarchy of the option classes is illustrated in Figure 1 and discussed below in Sections 2 and 3.

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2 OPTION CLASS I: RETAIN 10 CFR 60.113(a)(2) IN ITS PRESENT FORM

There are two lower-level options in this class: I (i) -- provide no guidance and do nothing to resolve the uncertainties or I (ii) -- prove guidance regarding the resolution of identified technical uncertainties. It remains to be determined if guidance can indeed resolve the uncertainties to the desired extent[3].

2.1 OPTION CLASS I (i): PROVIDE NO GUIDANCE

There are three lower level options in this class.

Option I (i) (A): Maintain the status quo; that is, provide no further clarification to the existing language. This option is the 'do nothing' option which obviously does not fulfill the objective of resolving the uncertainties in the rule.

Option I (i) (B): Specify a GWTT other than 1,000 years as permitted in 10 CFR 60.113(a)(2). This option also does not serve the objective of resolving the uncertainties because the present language of the RR is retained except for a change in the 1,000 years numerical value.

Option I (i) (C): Let the applicant petition for a GWTT other than 1000 years as is permitted in 10 CFR 60.113(b). Again this option fails to meet the basic objective of uncertainty reduction. Also, this option is counter to streamlining of the licensing process as the petition from the applicant may not be received until late in the process.

2.2 OPTION CLASS I (ii): PROVIDE GUIDANCE

Guidance may be provided in the form of a staff position, technical position or through other appropriate means. The guidance will be structured to provide unique meanings to the uncertain terms. Special care should be taken to assure that the guidance is not arbitrary but that it is based on accepted scientific principles. Also, special effort needs to be made so that no new uncertainties or ambiguities are introduced in the guidance. If this option is selected, a special task force will be required to develop the language of the guidance. Illustratively, guidance may consist of definitions of the ambiguous terms; e.g., 'fastest path of likely radionuclide travel' denotes that flow path which carries no more than x% of the total flux of water passing through the repository; where x for example may be 1. Some of the other options defined in Section 3 may also be reworded in the form of guidance. However, it should be noted that guidance has no force of law, as would a newly designed RR promulgated through rulemaking.

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[3] Only a partial resolution of uncertainty may be desired at this time in order to maintain flexibility in future decision making.

3 OPTION CLASS II: MODIFY THE REQUIREMENTS OF 10 CFR 60.113(a)(2)

The second basic category of options is to not retain the existing language of the GWTT rule. Two second level option classes are to either eliminate any requirement on the performance of the geologic setting or to keep a measure of the performance of the geologic setting in 10 CFR Part 60 but not as currently stated.

3.1 OPTION CLASS II (i): ELIMINATE 10 CFR 60.113(a)(2)

Under this option class, the GWTT rule would be eliminated and no alternative geologic setting subsystem performance measure would be provided by the licensing agency. Two lower level options are possible.

Option II (i) (A): The applicant would be required to set an alternative to the GWTT requirement. This alternative should in some sense ensure a minimum performance of the site subsystem as is required by the multi-barrier concept. This option is counter to the NRC streamlining process as it leaves the formulation of the requirement to the applicant.

Option II (i) (B): There would be no performance requirement for the geologic setting. If selected, this option will signal a major shift in NRC regulatory philosophy as a performance measure for a subsystem will be eliminated entirely. However, selection of this option will obviously eliminate all uncertainties associated with the GWTT RR.

3.2 OPTION CLASS II (ii): MODIFY THE GWTT REQUIREMENT

Two lower level classes can be associated with this class: II (i) -- the GWTT concept is retained although stated differently or II (ii) -- a different measure of the performance of the geologic setting is established. It is possible to allow the applicant the initiative for proposing an alternative to the current GWTT. This can be accomplished by adding the phrase "or some another appropriate performance measure to be approved by the Commission" after the words "... groundwater travel time" in 10 CFR 60.113(b). For the reasons stated before, such an option does not lead to streamlining of the licensing process.

Options in addition to those listed below may in certain cases also be formed by combining two (or more) of the identified options. For example, an option from Section 3.2.1 can be combined with an option from Section 3.2.2 to produce a performance measure for the geologic setting that contains a measure that is based on the GWTT concept and a measure that is based on an alternative concept. The number of such combinations are too numerous to be listed separately.

The options contained in this section can be applied to either: (i) pre-emplacement conditions or; (ii) post-emplacement conditions. If post-emplacement conditions are invoked,

one has the option of requiring that the measure apply either to only anticipated processes and events or to include unanticipated processes and events. However, the reader is reminded that the original intent of the subsystem performance requirements, as stated in the supplemental information to the final rule (NRC, 1983) was to apply these to no more than the anticipated processes and condition. In fact, the current wording of the GWTT RR is even more restrictive as this requirement applies only to pre-waste-emplacement conditions, not future anticipated states of the site.

3.2.1 Option Class II (ii) (A): Retain the GWTT Concept but Change the Current Language

Several options are proposed as part of this class.

Option II (ii) (A) (a): "The median pre-waste-emplacement GWTT from any point within the geologic repository to the accessible environment (as defined by the EPA) will be greater than x". Technical rationales can be developed for specific values of x. For example a value of 10,000 years can be rationalized based on the fact that the GWTT is not to be measured from the edge of the disturbed zone. The use of the term 'median' can be interpreted to mean that a statistical distribution of GWTT is to be developed and half of the (macroscopic) water particles are to have travel times longer than 10,000 years. Alternatively, it can be interpreted to mean that 50% of the water particles crossing the repository will have a travel time longer than 10,000 years. A second similar requirement may also be needed for gas flow.

Option II (ii) (A) (b): "The travel time of a macroscopic liquid particle from anywhere within the repository to a distance of x (e.g., 5) kilometers shall be at least y (e.g., 5,000) years". This wording omits the ambiguity associated with the terms "disturbed zone" and "fastest path of likely radionuclide travel". However, it still assumes that the travel time is associated with the travel of a 'macroscopic' water particle without defining the actual size of the particle.

Option II (ii) (A) (c): "The groundwater travel time under post-waste-emplacement conditions from the disturbed zone to the accessible environment shall be at least x (e.g., 5,000) years." This wording omits the ambiguity associated with the term "fastest path of likely radionuclide travel". However, for complete uncertainty resolution, the term 'disturbed zone' will have to be defined. This wording also leaves the rule incomplete as no mass (or volume) of fluid is specified. The 5,000 years may be rationalized on the basis that it is not associated with the fastest path anymore.

Option II (ii) (A) (d): "A minimum time (e.g., 10,000 years) for groundwater travel from the emplaced waste to the accessible environment will be based on the cumulative time of four separate physical events. The four physical events are: i) The creation of a drying zone around the emplaced wastes, ii) the subsequent return of moisture to the rock surrounding the waste canisters, iii) the travel time through the unsaturated zone and finally, iv) the travel time to the accessible environment by groundwater movement through the saturated zone" (based on a DOE suggested option, 50 FR 29641). DOE suggested this option as a method to apply the GWTT concept to the unsaturated zone. However, the language appears to be restricted only to liquid flow. Also, the wording of the rule is somewhat complicated.

Option II (ii) (A) (e): "The geologic repository shall be located so that the travel time of any groundwater flowing between the outermost waste container location and the accessible environment is at least 1,000 years." (Comment No. 434, NUREG-0804, 1983). Ambiguity associated with the term "disturbed zone" and "fastest path of likely radionuclide travel" is avoided in this option by specifying the travel path and the boundary conditions. However, an additional uncertainty is introduced by not specifying the conditions (anticipated or unanticipated) under which the calculation is to be performed.

Option II (ii) (A) (f): "The geologic repository shall be located so that pre-waste-emplacement groundwater travel times through the far field to the accessible environment are at least 10,000 years, as determined by the site specific physical properties and accepted numerical modeling procedures." (Source of option: Comment No. 448, NUREG-0804, 1983). Ambiguity associated with the term "disturbed zone" and "fastest path of likely radionuclide travel" is avoided in this option. Modeling conditioned with measured physical parameters is used to determine travel paths and velocities.

Option II (ii) (A) (g): "The pre-waste emplacement travel time of a macroscopic particle of water from any point within the repository to the accessible environment boundary shall be greater than x (e.g., 5,000) years with a probability of at least 0.9." This option proposes a probabilistic requirement and will require a stochastic analysis of ground water flow.

3.2.2 Option Class II (ii) (B): Do Not Retain the GWTT Concept As the Measure of Performance of the Geologic Setting

Concepts other than the groundwater travel time are available as a measure of the performance of the geologic setting. Options in this class are as follows.

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Option II (ii) (B) (a): "The geologic repository operations area shall be located so that the geologic setting, acting alone under anticipated conditions and processes will restrict the cumulative release of radionuclides to the accessible environment over a period of x (e.g. 10,000) years, to less than twice the limits allowed under 40 CFR Part 191, Appendix A". The basic idea of this option is to relate the performance of the site to the EPA standard. The actual proposed language however, shall have to be refined as the EPA rule includes not only release limits but also associated probabilities.

Option II (ii) (B) (b): "The geologic repository operations area shall be located so that the rate of liquid groundwater flux passing through the outer perimeter of the repository is less than x (e.g. 0.1) cubic meters per year per metric tons of heavy metal (MTHM), for the first y (e.g. 10,000) years after closure". This option implies a premium for placing as much HLW in the repository as possible, since allowable flow is in proportion to waste quantity.

Option II (ii) (B) (c): "The geologic repository operations area shall be located so that the curie flux across the accessible environment boundary will be less than x (e.g., 1 part in 10,000) per year of the total activity in the repository at y (e.g., 1,000) years". This option would require for its calculation that mass transport be considered which will bring into play the engineering design as well all issues of geochemistry.

Option II (ii) (B) (d): "The cumulative groundwater flow from the repository to the accessible environment for x (e.g., 10,000) years shall be less than y (e.g., 100) cubic meters for pre-emplacement conditions." The rationale for the y quantity will have to be based on toxicity of radionuclides having low sorption, high solubility and long half-life.

Option II (ii) (B) (e): "The radionuclide flux shall be less than x (e.g., 10) curies per year above background for y (e.g., 10,000) years." This option will require calculation of transport of all radionuclides.

Option II (ii) (B) (f): "There shall be a high level of confidence that all but a very small fraction of the groundwater flow paths will have hydraulic conductivities and porosities such that for any anticipated hydraulic gradient, the groundwater travel time will be at least 1,000 years" (Chu et al., 1983). The use of the words 'high level of confidence' and 'very small fraction' introduces ambiguities into the RR.

Option II (ii) (B) (g): "The geologic repository shall be located so that the areal mass flux density of radionuclides at the boundaries of the accessible

environment shall not exceed x (e.g., 0.1) curies per square meter per year over background radiation for y (e.g., 10,000) years after permanent closure". This option would remove ambiguity associated with the terms "disturbed zone" and "fastest path of likely radionuclide travel" but would require the determination of a source term and an assessment of the geochemistry of the site.

Option II (ii) (B) (h): "The geologic setting is sound (or acceptable) if it can be demonstrated that the pre-waste-emplacement residence time is greater than x (e.g., 5,000) years." This option will require a definition of the 'residence time' which may be defined as the time that a liquid (and/or gas) particle resides in the geologic setting before exiting the accessible boundary.

Option II (ii) (B) (i): "The cumulative mass flux of a nonreactive gas passing through the repository to the accessible environment boundary shall be less than x (e.g., 1 kilogram) over a period of y (e.g., 10,000) years. This option can be stated in terms of a flow rate.

Option II (ii) (B) (j): "There should be a high level of confidence (e.g., 90%) that all but a very small fraction of groundwater flow paths (e.g., 1%) will have hydraulic conductivities and porosities such that for any reasonably anticipated hydraulic gradient, the groundwater travel time will be at least 1,000 yrs." (Source of option: NUREG/CR-3111 pg 350).

Option II (ii) (B) (k): "For a saturated site, the sustained yield of water from all zones below the repository shall be less than x (e.g., 1 cubic foot per day)." This option can actually be tested in the field but it cannot be applied to unsaturated sites.

Option II (ii) (B) (l): "For an unsaturated site, the rate of pre-waste emplacement seepage into the repository shall be less than x (e.g., 1 mm) per year." It may be possible to estimate this quantity by measurement also.

Option II (ii) (B) (m): " The mean effective permeability, at a scale of x (e.g., 10) cubic meter or larger, of the region between the repository and the accessible environment boundary shall be less than y (e.g., 10^{-8}) meter square. In addition, the 99th percentile of permeability at the same scale shall be less than z (e.g., 10^{-10}) meter square." Again this performance measure can depend to a very large extent on field measurements. Because permeability (rather than hydraulic conductivity) is the performance measure, it is applicable both to liquid and gas flow, as well as to saturated and unsaturated sites.

Option II (ii) (B) (n): "The total porosity of the region between the repository and the accessible environment boundary shall be less than x (e.g., 10^{-4}) at a scale of y (e.g., 10) cubic meters or larger."

Option II (ii) (B) (o): "The liquid flux passing through the fracture zones should be a fraction (e.g. 1 percent) of the total flux." This option basically limits the extent of flow through the fractures at the site.

4 SUMMARY AND RECOMMENDATIONS

There are numerous options for resolving the technical uncertainties that have been identified in the GWTT RR. These options vary widely with respect to their simplicity, completeness, extent to which they cover the performance aspects of the site, and difficulty of their compliance demonstration method. A two-step procedure for selecting the preferred option is recommended. The first step of this procedure should perform a screening based on well formulated qualitative criteria. Such criteria are currently under development. This screening procedure should select a small number (perhaps half a dozen) options which should then be explored in detail in a quantitative manner. The quantitative analysis should provide the required technical basis for the final selection.

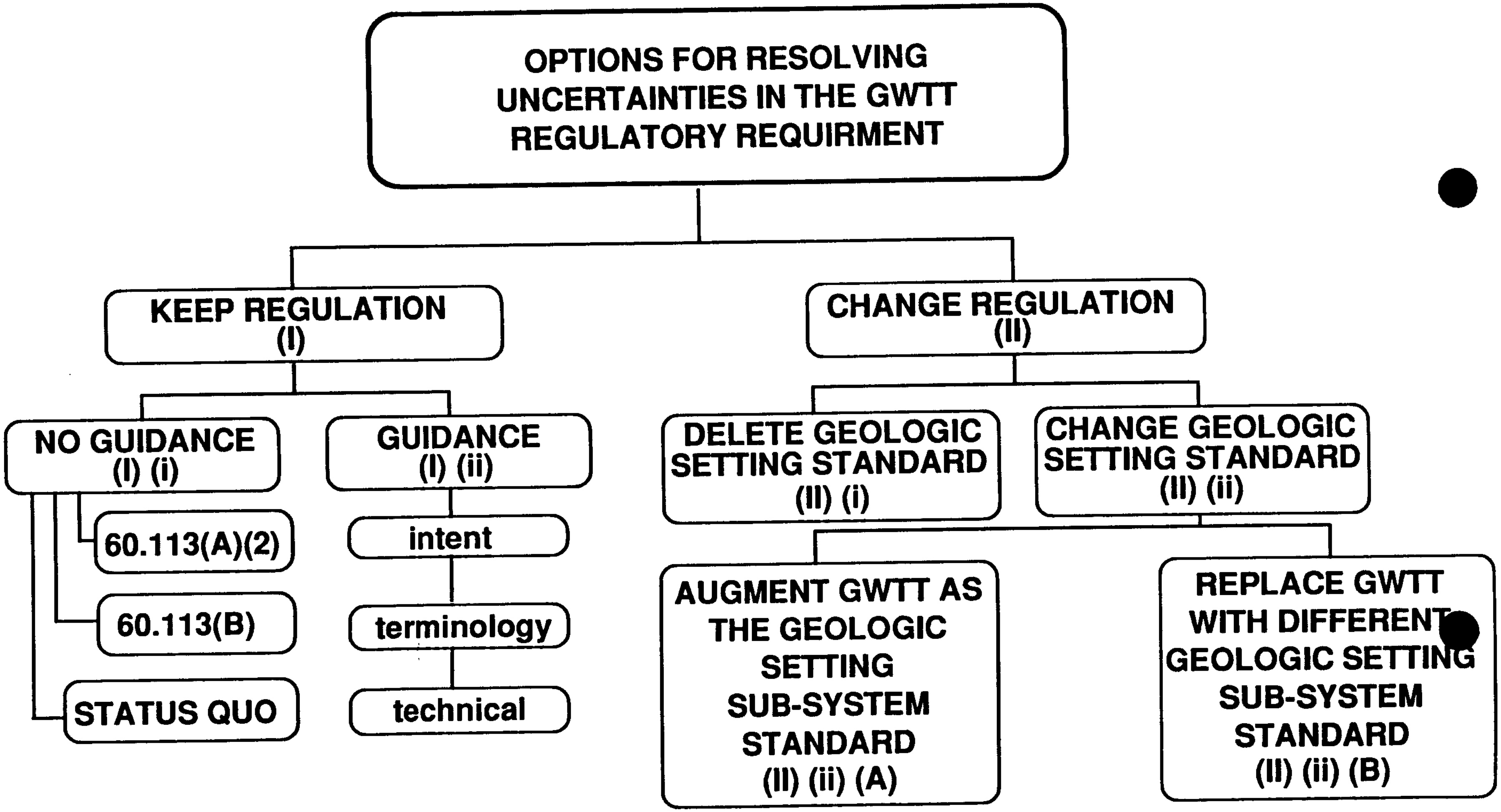

Figure 1. Hierarchy of the Options

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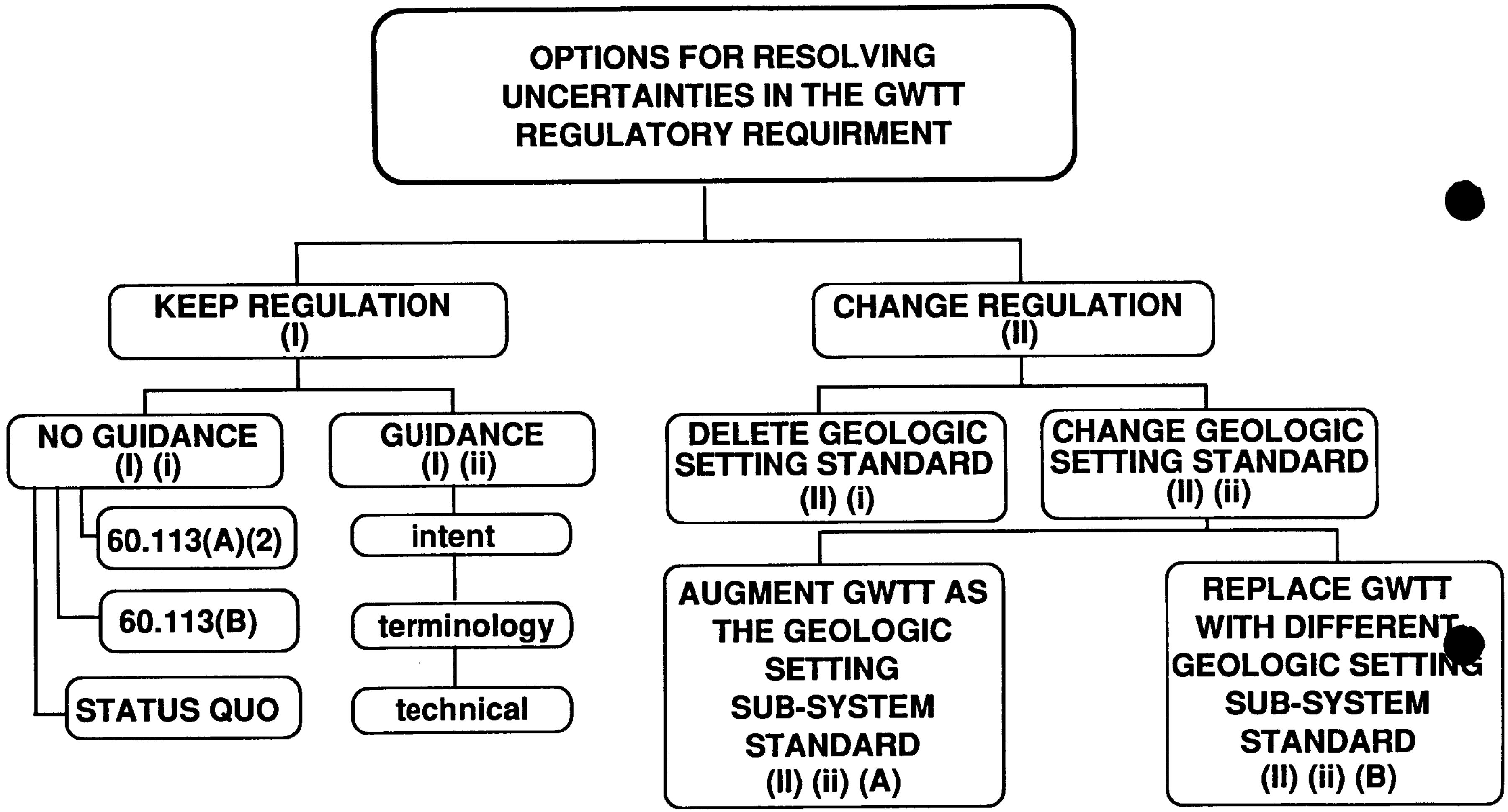

Figure 1. Hierarchy of the Options