RECENT DEVELOPMENTS IN THE GERMAN APPROACH TO RADIOACTIVE WASTE DISPOSAL

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ABSTRACT

The Federal Republic of Germany intends to dispose of all types of radioactive waste in deep geological formations. This approach comprises spent fuel elements, vitrified fission product solution, nuclear power plant operational and decommissioning waste as well as spent sealed radiation sources and miscellaneous waste originating from small waste generators. The Atomic Energy Act gives the responsibility for the disposal of radioactive waste to the Federal Government with the Bundesamt für Strahlenschutz (BfS - Federal Office for Radiation Protection) as the legally responsible authority. All other radioactive waste management procedures, i. e. spent fuel storage, reprocessing, conditioning, transportation and interim storage are within the responsibility of the waste generators. The federal states must construct and operate regional collecting depots for the interim storage of radioactive waste originating, in particular, from radioisotope application in industry, universities and medicine.

As a result of the September 1998 federal elections, a coalition government of the Social Democrats and Alliance ´90/The Greens was formed. The new Federal Government makes a pronounced change in energy policy, the most important feature of which is the abandoning or phasing out of nuclear energy. It is intended to irreversibly phase out nuclear energy use for electricity generation. This shall be performed in a gradual procedure including so-called consensus talks with representatives of the utilities as well as legislative measures.

INTRODUCTION

In the Federal Republic of Germany, the use of nuclear energy especially started with the operation of the first nuclear power plant in 1960. Since the early sixties, i. e. from its very beginning, the German radioactive waste disposal policy has been based on the decision that all types of radioactive waste are to be disposed of in deep geological formations. Such a decision is only realistically acceptable if a barrier to radionuclide releases exists which remains effective over very long periods of time radionuclides need to decay significantly. Thus, vitrified fission product solution from reprocessing and spent fuel elements as well as spent sealed radiation sources and miscellaneous waste from small waste generators are affected by this decision. It also applies to alpha bearing waste originating in particular from reprocessing facilities, nuclear research establishments or the nuclear fuel cycle industry. Near-surface disposal or shallow land burial is not practised in Germany because of high population density, climatic conditions and existing appropriate deep geological formations.

GERMAN RADIOACTIVE WASTE DISPOSAL POLICY

Basic Aspects of Radioactive Waste Disposal

In the Federal Republic of Germany the "Safety Criteria for the Disposal of Radioactive Waste in a Mine" [1] include the basic aspects which must originally be taken into account to achieve the objective of disposal. They qualitatively specify the measures to be taken to achieve the protection goal of disposal and define the principles by which it must be demonstrated that this goal has been reached.

The Safety Criteria comprise the most important features characterising the German approach to disposal (basic concept) and the respective philosophy employed:

(a) Radioactive waste is disposed of in a suitable deep geological formation, this being an approach to ensure, in particular, the long-term and safe isolation of the radioactive waste from the biosphere.

(b) Only deep geological disposal is discussed in the Safety Criteria. Under these assumptions, basically, no other measures will be necessary after the completion of waste package emplacement, backfilling and sealing as well as after having the repository closed.
(c) The Safety Criteria relate to the disposal of radioactive wastes, which is defined as maintenance-free, indefinite and safe disposal of these wastes [1]. Regarding disposal on a large technological scale, procedures and measures are to be applied in which the retrievability of the waste is not necessary. Thus, retrievability had originally not been considered in the German waste disposal concept.
(d) The concept to renounce retrievability is of advantage especially with regard to radiation protection as well as to safeguards aspects. For example, the backfilling and sealing of individual disposal rooms or disposal fields filled with waste packages contributes to a reduction of the radionuclide concentration in the exhaust air already in the operational phase of a repository, thus reducing the radiation exposure of the staff of a repository and its vicinity.

The Safety Criteria were issued in 1983 and are at present being revised on behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU - Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit,). BMU is the competent federal authority for nuclear safety, radiation protection and waste management in Germany. The overall aim of this revision may be outlined as follows:

(a) Survey of the international status of the development of safety criteria for the disposal of radioactive waste and its evaluation as compared to the German situation.
(b) Consideration of respective activities being performed by international institutions such as the International Atomic Energy Agency (IAEA) (e.g., the RADWASS programme and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management), the Organisation for Economic Co-operation and Development/Nuclear Energy Agency(OECD/NEA) and the International Commission for Radiation Protection (ICRP).
(c) Preparation of proposals for the actualisation and harmonisation of the Safety Criteria, in particular according to the international status and the experiences resulting from the Konrad repository licensing procedure.

On an international level, irrespective of the research already lasting for more than three decades, methodical-conceptual questions have been discussed intensively. The development of the state-of-the-art of science and technology has shown that the previous Safety Criteria regarding the fulfilment of the required precaution against damage must be revised. This is also expressed in recent international publications, e.g. in the documents, "Confidence in the Long-Term Safety of Deep Geological Repositories - Its Development and Communication (OECD/NEA 1999), "Geological Disposal of Radioactive Waste: Reviews of Developments in the Last Decade" (OECD/NEA 1999), "Safety Indicators, Complementary to Dose and Risk, for the Assessment of Radioactive Waste Disposal" (IAEA 1999) and "Disposition of High-Level Radioactive Waste through Geological Isolation - Development, Current Status, and Technical and Policy Challenges" (NRC 1999). Important questions like the possibilities to assess long-term safety and human intrusions are also currently being discussed in depth in the ICRP Committee 4. In several countries, the increasing concretisation of waste management planning and site-specific findings has led to this development in recent years which is reflected, among others, in the aforementioned documents.

Additionally, there are new scientific findings which are of immediate importance to a site in salt, e. g. the problem gas generation through corrosion and microbial decomposition, nuclear criticality, safeguards, multi-barrier concept and chemical-toxic components.

Against this background, the current state-of-the-art of science and technology has to be taken as a basis in a licensing procedure which can probably be expected in some decades for a repository for high-level wastes. This requires that the previous criteria regarding the fulfilment of the necessary precaution against damage must be revised against the background of the international discussion and new scientific findings.

Repository Projects/Repository

According to the German disposal concept, all radioactive waste has to be emplaced in a repository constructed and operated in deep geological formations. As liquid and gaseous wastes are excluded

from disposal in such a mine, only solid or solidified radioactive waste is accepted. According to the 1979 German radioactive waste management concept, two sites have been considered for disposal:

(a) The abandoned Konrad iron ore mine in the Federal State of Lower Saxony has been investigated for disposal of radioactive waste with negligible heat generation, i. e. waste packages which do not increase the host rock temperature by more than 3 K on an average. At a depth of 800 m to 1,300 m waste packages are planned to be emplaced in disposal rooms using the stacking technique. The emplacement of up to 650,000 m^3 waste package volume has been planned. Operation of the repository is scheduled for at least 40 years. A total activity in the order of 10^{18} Bq and an alpha emitter activity of about 10^{17} Bq are anticipated in this facility.

(b) The Gorleben salt dome in the north-east of Lower Saxony is being investigated for its suitability to host a repository at depths between 840 m and 1,200 m for all types of radioactive waste, mainly for heat-generating radioactive waste originating from reprocessing and spent fuel elements. The accumulated inventory of beta/gamma and alpha emitters to be emplaced within an operational period of about 70 years is estimated to be in the order of magnitude of 10^{21} Bq and 10^{19} Bq, respectively.

Short-lived low and intermediate level radioactive waste with an alpha emitter concentration of up to $4.0 \cdot 10^8$ Bq/m^3 originating from the operation of nuclear power plants and the application of radionuclides in research, medicine and industry in the former German Democratic Republic was disposed of in the Morsleben repository, an abandoned salt mine located near the village of Morsleben in Saxony-Anhalt. By Febuary 1991, radioactive waste with a total volume of approximately 14,500 m^3 and about 6,700 spent sealed radiation sources were disposed of. Since German unity which took place on October 3, 1990, the Morsleben facility has the status of a federal repository in the sense of section 9a (3) of the Atomic Energy Act.

Emplacement of radioactive waste in the Morsleben repository was stopped in February 1991 because questions with regard to safety and licensing had been raised. On January 13, 1994, emplacement operations were resumed. From that date through September 28, 1998, radioactive waste with a total volume of 22,320 m^3 and 394 spent sealed radiation sources were disposed of. The activity of beta/gamma emitters emplaced in that period of time totals $9.1 \cdot 10^{13}$ Bq, of which $8.0 \cdot 10^{10}$ Bq are alpha emitters.

According to the September 25, 1998 order of the Superior Administrative Court of the federal state of Saxony-Anhalt, BfS has to immediately stop further radioactive waste disposal in the so-called eastern emplacement field of the Morsleben repository. This will be effective until the final court decision will be made. Due to the results of the BfS' examination of the court order of September 25, 1998 (preliminary decision) it was decided to stop generally waste emplacement in the Morsleben facility for the time being. Thus, the last waste emplacement operations were carried out on September 28, 1998. Since that time no waste packages have been disposed of in the Morsleben repository.

NEW DEVELOPMENTS IN RADIOACTIVE WASTE MANAGEMENT AND DISPOSAL

In Germany, federal elections took place on September 27, 1998. As a result, a coalition of the Social Democrats and Alliance '90/The Greens came into power. The political aims of the new Federal Government are given in the coalition agreement of October 20, 1998 [2]. The most important feature of the new energy policy is the abandoning or phasing out of nuclear energy. Thus, the new Federal Government makes a pronounced change compared to the previous energy policy. It is intended to irreversibly phase out nuclear energy use for electricity generation. This shall be perfomed in a stepwise procedure: In a first step consensus talks with representatives of the utilities are envisaged aiming at unanimous decisions on a new energy policy, further steps to definitely terminate the use of nuclear energy for electricity production, and to establish an appropriate radioactive waste management and disposal concept. If a consensus will not be reached, then, in a second step respective legislative measures will be taken.

COALITION AGREEMENT OF OCTOBER 20, 1998

Energy policy is addressed in particular in chapter 3 "Modern Energy Policy" of the coalition agreement [2]. Given below is subchapter 3.2 "Abandoning Nuclear Energy".

Abandoning Nuclear Energy

The abandoning of the peaceful use of nuclear energy will be comprehensively and irreversibly regulated by law within this parliamentary term. For this, the coalition parties agree upon the following stepwise procedure.

In a first step, a first amendment of the Atomic Energy Act will be introduced as part of the 100-day-programme with the following content:

(a) Cancellation of the support purpose (of nuclear energy use as given in the Atomic Energy Act).
(b) Introduction of an obligation for a safety check, to be submitted within one year.
(c) Clarification of a regulation regarding the burden of proof in the case of proven suspicion of danger.
(d) Restriction of waste management to direct disposal.
(e) Cancellation of the 1998 amendment of the Atomic Energy Act (with the exception of the implementation of European Union law).
(f) Increase of financial security.

In a second step, the new Federal Government will invite the utilities for discussions to agree upon a new energy policy, steps for the abandoning of nuclear energy and related waste management issues, and - if possible - to find a consensus. The new Federal Government sets itself a temporal framework of one year following assumption of office.

Following this deadline, in the third step, the coalition will introduce a law with which the abandoning of the use of nuclear energy will be regulated without compensation; to achieve this, the operating licences will be limited in time. Measures required for waste management will also be adapted.

As to waste management, the coalition parties agree the following:

(a) The coalition parties agree that the previous management of radioactive waste concept has failed with regard to its content and does no more have a technical basis. A national waste management plan for the legacy of radioactive waste will be developed.
(b) A single repository in deep geological formations is sufficient for the disposal of all types of radioactive waste.
(c) The disposal of high-level waste (HLW) by the year 2030 is the time-dependent target for the disposal of all types of radioactive waste.
(d) There are doubts with regard to the suitability of the Gorleben salt dome. Therefore, its exploration shall be interrupted and further sites in various host rocks shall be investigated for their suitability. The final site shall be selected based on a following comparison of the sites.
(e) The emplacement of radioactive waste in Morsleben shall be terminated. The plan-approval (licensing) procedure remains restricted to decommissioning.
(f) Basically, each operator of a nuclear power plant is obliged to construct interim storage capacities on site. Spent nuclear fuel may only be transported if no licenced interim storage capacity exists at the nuclear power plant site and if the power plant operator is not responsible for this. The interim storage facilities shall not be used for disposal purposes.

The coalition agreement is the basis for all respective activities, discussions and planning work presently initiated and/or carried out in Germany. With respect to disposal it should be pointed out, that, correspondingly to the internationally prevailing opinion, the Federal Government considers the emplacement of radioactive waste in deep rock formations of the earth's crust the best possibility to fulfil the precaution against damage according to the state-of-the-art of science and technology which is required by the Atomic Energy Act.

RE-EXAMINATION OF THE GERMAN DISPOSAL PROGRAMME

The coalition parties of the German Federal Government, the Social Democratic Party and Alliance ´90/The Greens stated in their coalition agreement that the phasing out of nuclear energy for electricity generation must be regulated within the present legislative period. At present, an Inter Ministerial Working Group is reviewing the legal framework conditions for achieving this goal without claims for compensation by the affected utilities. The preferred way would be a consensus with the utilities, especially with respect to the future operating life time of the existing nuclear power plants and a new national waste management plan.

This plan must be based on a definite time schedule for ending the use of nuclear power. The BMU has set up a special working group to develop repository site selection criteria and respective procedures on a scientifically sound basis. The time needed for this task is estimated to be about 3 years: In February 1999, the working group "Selection Procedure for Repository Sites" started its work. First results are expected in 2000. An in-depth discussion of the proposals with the public is planned from 2001 on, so that the competion of work can be expected in 2002. The criteria and procedures still to be developed aim at finding the most suitable site in different host rocks in Germany.

The German Federal Government is envisaging the disposal of all types of radioactive waste in one geological repository. Such a repository should go into operation by 2030.

The future generation of radioactive waste depends on the further use of nuclear energy in Germany. Estimations and prognoses of the waste which is expected to be produced have been performed within the scope of scenarios with different conditions. Here, scenarios are considered with the nuclear power plants being operated for 50, 35, and 25 years [3]. In the different scenarios the waste package volume cumulated in 2080 varies between approximately 300,000 m^3 and approximately 340,000 m^3. This would be a span of approximately 12 % which, taking into account the assumptions and periods prognosticated, is only marginal. The differences result mainly from the different amounts of operational waste produced by the nuclear power plants. On average, 75 m^3 of operational waste are produced per year and nuclear power plant.

Against the background of the life-time of the nuclear power plants that have been decommissioned up to now which is clearly lower than projected, of the peaceful use of nuclear energy and new conditioning technologies, which is clearly below previous plans, the total waste volume to be expected in future has clearly decreased compared to former estimations. This trend will increase further with the abandoning of the use of nuclear energy. Therefore, already today it is clear that, with regard to volume only, it will be possible to dispose of all waste produced until the end of the periods of operation of the nuclear power plants in one repository.

Impact on the Gorleben and Konrad Repository Projects and the Morsleben Repository

The Gorleben salt dome has been investigated for its suitability for hosting a repository for all types of radioactive waste, particularly HLW originating from reprocessing and spent fuel (direct disposal). For this purpose, two shafts were sunk. Both shafts were interconnected at a depth of 840 m on October 21, 1996. At this depth the exploration drifts and galleries are being excavated.

The aforementioned Inter Ministerial Working Group is favouring a moratorium with respect to the underground investigation in Gorleben. The consensus talks with the utilities, however, have not reached a common position. Though there are doubts with respect to the suitability of the Gorleben site, it is not considered to be unsuitable and will be included in the future site selection process. Thus, underground site investigations may be resumed in a couple of years or given up completely. Meanwhile the operation of the exploratory mine will be restricted to maintenance work to keep the mine open safely.

The former Konrad iron ore mine is planned for disposal of radioactive waste with negligible heat generation., i. e. low-level waste (LLW) and intermediate-level waste (ILW). The licensing procedure is nearly finished; nevertheless a positive decision by the competent licensing authority (federal state of Lower Saxony) is still pending. The future of the Konrad repository project will presumably be discussed within the consensus talks. There is scientific evidence that a separate disposal of low- and

intermediate-level waste may have special advantages from a safety point of view (e. g., with respect to gas generation in the post-closure phase). BfS sees no fundamental legal or safety reasons why the Konrad repository could not be licensed. Whether Konrad will really still be needed from the point of view of the utilities of whether the utilities prefer only the provision of just one repository for management reasons, will be discussed in the consensus talks. Relating to this, the waste generators made different statements during the last years.

After a decision by the Superior Administrative Court of Saxony-Anhalt on September 25, 1998 all waste emplacement in the Morsleben repository has been stopped. The repository is not likely to resume operations. An application for the licensing procedure for decommissioning has been filed on May 9, 1997. The assessment of the isolation potential within this procedure is of special importance. The safety assessment was originally based on a preliminary backfilling and sealing concept; more detailed site specific information and respective safety analysis proved this concept not to be acceptable. Thus, two alternative concepts are being developed but, up to now, have not yet given sufficient confidence in meeting the safety objectives.

The National Waste Management Plan

Since the beginning of the sixties all it has been unanimously agreed upon in Germany that geological disposal is the preferred option for safe disposal of all types of radioactive waste. Alternatives like the very long-term storage or partitioning and transmutation are not part of the national waste management plan.

With respect to the realisation of this plan, however, the time perspective for HLW disposal is by the year 2030. The time perspective for performance assessment is one of the problems which have to be solved satisfactorily. The following facts are to be faced [4]:

(a) The average total activity, heat production and toxicity in the repositories will be higher than those in natural enrichments even after about a hundred thousand years.
(b) The relatively high concentration of the toxic material in the spent fuel is of special importance for direct radiation. Here, even after 10^6 years an absorbed dose rate from gamma radiation was calculated to be about $6 \cdot 10^{-4}$ Gy/h at a distance of 1 m from the fuel element. This exceeds the intervention level of $5 \cdot 10^{7}$ Gy/h for the tailings from mining and milling of the Wismut company by three orders of magnitude.
(c) An unlimited demonstration period is, however, not possible with the calculation models and methods currently available. The formulation and application of so-called safety indicators are proposed.

The OECD/NEA report "Confidence in the Long-term Safety of Deep Geological Repositories - Its Development and Communication" [5] addresses many aspects presently discussed within the national waste management plan. With respect to the three basic elements of confidence in decision making, in Germany only one (Confidence in the appropriateness of geological disposal) is met, whilst confidence in long-term safety aspects and in procedures and regulations is still lacking. The requirement that "the arguments must give sufficient confidence, or reasonable assurance, to the decision makers within the relevant organisations that the benefits following from a correct decision outweigh the risk and consequences of the decision proving to be incorrect" is an important reason for a moratorium for Gorleben.

Retrievability and human intrusion are additional topics which have not been solved finally. Many national and international parties are now reconsidering the strategic merits of ongoing monitoring and possible retrieval as opposed to a programme that involves closure of a repository and absence of planned activities thereafter. The German approach to retrievability is adressed in more detail below. Present mining technology does not allow retrieval of all the waste in an HLW repository as planned in the Gorleben salt dome for about 1000 years according to thermal aspects. After that period of time the temperatures in the area of the emplacement fields will be in the order of magnitude of about 100 °C thus allowing the retrieval of waste packages. Human intrusion scenarios and the resource potential of sites are other topics discussed internationally in favour of including these scenarios in making a safety case.

The decision making process is closely linked to all the aspects mentioned above. Of special importance is the critique on the previous site selection process for the Gorleben site. The site

selection procedures need a clear structure and the relevant procedural processes have to be assessed. Within this context, the role and impact of the regulatory aspects on the evaluation of the site and the total repository system need to be clarified. Thus, appropriate solutions are to be prepared being imperative to the successful development and acceptance (public and political) of a repository.

Aspects on Retrievability/Recoverability

The defining characteristic of the post-closure status is that no further engineering measures are expected to be necessary in order to ensure proper future performance of the disposal facility. In a geological repository, the post-closure phase pertains to the period following the final shaft sealing and surface facility decommissioning. Retrievability as a design base may thus be in conflict with the post-closure status desired for the compliance with the aforementioned objective and principles of radioactive waste management. On the other hand, the ethical requirement of not foreclosing decisions and responsible actions including recoverability/retrievability of future generations may be easier to meet. Thus, final conclusions on retrievability will have to consider scientific/technical features and in particular ethical aspects. At present, the German radioactive waste management and disposal concept is being reviewed and will be adopted according to political decisions, new findings and specific evaluations. In particular, the assessment basis for the selection of repository sites is being reviewed and revised site selection criteria, including a scientifically sound procedure for final site selection, will be developed. In this context, among other things, issues on, e. g., retrievability, gas production, role of natural and engineered barriers as well as human intrusion will be examined. Thus, as to the present evaluation of retrievability, it may be concluded that the protection and limitation of burdens to future generations basically require a filled and sealed repository without any longer surveillance periods during the post-closure phase. Nevertheless, a perfect technical system is not - and will not be - available. As a consequence, future generations should be offered the possibility to take decisions on their own, to perform responsible actions including further safety-related assessments as well as measures on retrievability and/or recoverability. Thus, a repository in a geological formation must be planned, operated, backfilled and finally sealed in such a way that a subsequent control/surveillance and repairability/retrievability will not be necessary, but not be impossible (anthropogenic deposit). The respective prerequisites must be examined in detail, clearly distinguishing between the operational and post-closure phase of a repository. In addition to prevailing planning work, the conceptual design of a repository, including the intention to retrieve the waste packages as a design base requirement, is to be scrutinised. In this connection, two different possibilities are to be taken into account:

(a) The retrievability of waste packages during the operational phase.

(b) The retrievability of waste packages from a sealed repository during the post-closure phase.

As to the latter case, it should be mentioned that because of the time- and heat-dependent characteristics of rock salt an investigation into the feasibility to retrieve waste packages from a sealed repository using rock salt as host rock needs further detailed investigation.

Last but not least the recommendations and results of the November 4-5, 1999 Irvine workshop [6], will have to be taken into account. According to the pre-conference discussion papers many parties within the international HLW community are now reconsidering the merits of a strategy based on long-term (more than 100 years) monitoring and retrieval, as opposed to a program that involves closure of a repository and no retrieval. All repositories will be monitored after closure for some time. Several factors motivate continued study and monitoring rather than expediting repository closure as soon as the HLW and spent fuel have been emplaced. First, the response of the geological site and of the engineered barriers to the waste may lead to adjustments in the containment system. Second, provisions for ongoing monitoring may be viewed by the publics as preferable, so that if very unlikely containment failures or unexpected events should occur at the repository, effective and timely action can be taken to avoid releases of radioactivity into the biosphere. Third, retrievability may become desirable in the future because of the considerable energy value of components such as plutonium in the spent fuel.

The counter arguments are that safe disposal is already now feasible and that delaying closure for long time presents a greater hazard. For example, operational expertise and funding in the future are not guaranteed. Retrieval from a closed geological repository remains in principle possible for very long times. Nevertheless, it may be appropriate to consider strategies for extending the time between

emplacement of waste and closure of a repository, and to regard an underground repository in a deep geological formation as a monitored, retrievable HLW storage facility, until sufficient confidence in its safety can be developed and the repository closed.

Non-Radiological Groundwater-Related Safety Aspects

According to existing German legal water regulations, in radioactive waste disposal, attention must be paid not only to radiological impacts but also to chemical impacts of certain waste constituents. For instance, in order to demonstrate the safety of a geological repository, particularly in its post-closure phase, possible releases of organic and inorganic contaminants via the water path, resulting in a pollution of near-surface groundwater, are to be investigated. Thus, in addition to an assessment of radiation exposure and radiological impacts during the operational and post-closure phases of such a facility, it has to be clarified whether non-radioactive toxic substances in the waste packages present an additional long-term hazard to future generations. In this context, it must be recognised that radionuclides are the minor mass fraction in the waste to be disposed of. The major mass fraction is made up of non-radioactive organic and inorganic material including chemotoxic substances. A complete site-specific safety assessment must, therefore, cover hazards and impacts associated with both, radioactive and non-radioactive constituents of the waste packages to be disposed of. The procedure and assessment of non-radiological groundwater-related impacts in radioactive waste disposal were successfully demonstrated, for the first time, within the licensing procedure for the German Konrad repository project [7].

CONCLUSIONS

Having the present radioactive waste disposal-related situation in mind, it is to be recognised that future developments and decisions will have to be extended to include further important aspects and, finally, to enhance acceptance and confidence in safety-related planning work as well as proposed radioactive waste management and disposal solutions. In particular, seeking consensus on the safety of radioactive waste management and disposal, including the respective procedures and steps to achieve this, might accomplish convergence and, thus, contribute to majority support.

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