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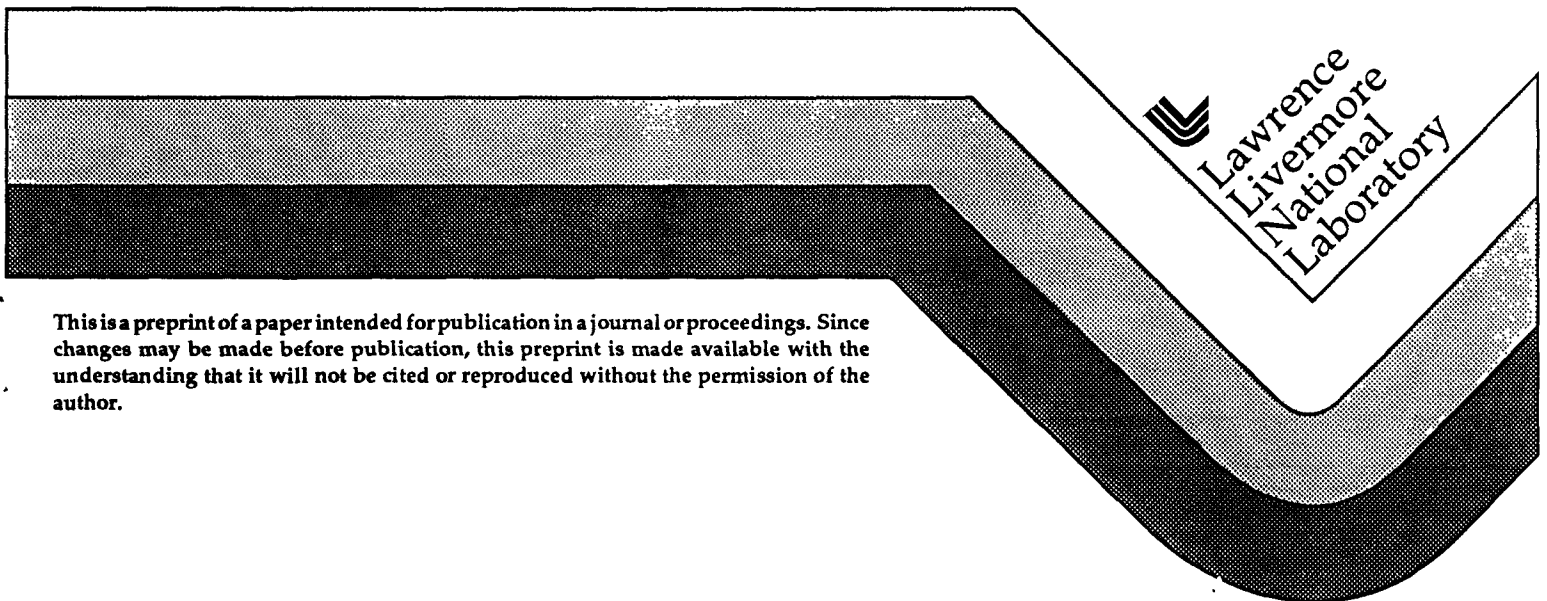
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L. A. Glenn
R. A. Heinle
B. Moran
J. Rambo
B. G. Roth

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KUCHEN: AN EXPERIMENT TO EVALUATE DECOUPLING IN HIGH-ASPECT-RATIO CAVITIES *

L. A. Glenn, R. A. Heinle, B. Moran, J. Rambo and B. G. Roth

University of California

Lawrence Livermore National Laboratory

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ABSTRACT

It has been argued that even if cavity-decoupled nuclear explosions are a theoretical evasion scenario, the size of the cavity required may be so large as to preclude their use, except possibly in salt. For example, to obtain a decoupling factor of 50 or more would require a cavity radius of at least $20 \text{ m/kt}^{1/3}$. Various theoretical studies have shown, however, that spherical cavities may not be necessary, and that ratios of length-to-span of 10-20 might be used without significant loss of decoupling capability so long as the volume is maintained. This means, for example, that if a tunnel with cylindrical cross section were employed to decouple a 1 kt explosion, the tunnel radius would decrease from 20 m to 8.1 m with an aspect (length-to-diameter) ratio of 10 and to 6.4 m with an aspect ratio of 20.

At NTS, we intend to take advantage of the readiness effort activities and funding to perform mid-scale chemical-explosion decoupling experiments in an event called KUCHEN that is scheduled for the spring of 1995. We have identified an 8 ft-diameter hole, 350 ft deep in area 9 (U9cu) that is available for these experiments. Our plan is to conduct two tamped shots and at least one decoupling shot in this hole. The explosive charge will be on the order of 50 kg and the aspect ratio will be in the range 10-15. Details of the proposed experiments are discussed.

* Work performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under contract #W-7405-Eng-48

INTRODUCTION

Cavity decoupling is acknowledged to be a major threat to successful verification of a CTBT; it is well known that kiloton-sized nuclear explosions are not likely to be identified if this technique is employed. Cavity decoupling could be an even greater challenge if decoupling can occur in elongated cavities. This would allow for easier mining in more materials, more available sites throughout the world, more widely available expertise, and possibly make identification even more difficult due to the shear waves that would be generated (spherical explosion sources do not produce primary shear waves but these are generated by earthquakes).

The question arises as to how well elongated cavities actually would perform. Stated more precisely, we are interested in the degradation of decoupling performance relative to spherical cavities of the same volume. The reason to expect performance degradation is easy to understand and relates to the reason why decoupling works in the first place. The long-period seismic amplitude resulting from an underground explosion is proportional to the asymptotic value of the reduced displacement potential (ϕ_∞) or, in physical terms, to the permanent change in volume measured anywhere beyond the range at which the outgoing wave has become elastic (Latter, Martinelli and Teller, 1959). It is known that ϕ_∞/W (where W is the explosion yield) is a function of the initial cavity volume and that increasing by pre-excitation the initial scaled radius, $r_0W^{-1/3}$, so that it is just large enough to preclude inelastic behavior in the surrounding rock, will result in a minimal seismic signal (Latter *et al.*, 1961). The key point here is that it is important to preclude inelastic behavior, since this produces larger displacements than would obtain if the cavity-wall material response were strictly elastic. Now clearly, the degree of inelastic response (plasticity or fracture) will increase the closer the explosive is to the cavity wall even if the overall volume is invariant. When the cavity is aspherical, the explosion products will contact the nearest surfaces of the cavity first and the local stresses thereby induced in the cavity wall will be much larger than if the wall was everywhere equidistant from the explosion source. In the limiting case of a very long cylinder, the effect of the initial volume would be negligible and the system would behave like a tamped explosion, with no decoupling achieved.

As the length-to-diameter (aspect) ratio, \mathcal{R} is varied between the sphere and the line source, i.e., when $1 \leq \mathcal{R} < \infty$, the decoupling factor, f , will vary from the maximum possible value for that volume (which will depend on the type of explosive used and the properties of the surrounding rock) to unity, the latter value signifying no decoupling. Glenn and Rial (1987) performed calculations of a nuclear explosion in salt in which \mathcal{R} was in the range 10-20 and found that f was degraded by less than a factor of 2 when compared to an equivalent volume spherical cavity. Stevens *et al.* (1991) did a number of calculations in both salt and granite, with ellipsoidal geometry and an aspect ratio of 4, and found very little difference when the results were compared with

similar calculations done in spherical geometry. Apart from these studies, and several experiments with relatively low aspect ratio cylindrical systems (to be reported on at this symposium; see for example Reinke *et al.*), no other information is available. To begin to fill in the gap, we have designed an experiment to examine decoupling at high aspect ratio. The experiment actually consists of at least three separate explosions, two of which will be tamped, which are collectively labeled KUCHEN.

The KUCHEN event might be called a target of opportunity, since the Lawrence Livermore National Laboratory is tasked with maintaining the readiness to perform underground explosions at the Nevada Test Site (NTS). As part of this readiness mandate, the Laboratory is required to exercise the skills that are necessary to install and contain explosion canisters under relatively realistic conditions, a process that has been determined to involve the actual detonation of small quantities of chemical explosives. By taking advantage of the readiness program, we have been able to design a decoupling experiment that can be performed at very little additional cost. In what follows, we will describe the experiment in some detail, and give some preliminary estimate of the expected results. The KUCHEN event is presently scheduled to take place in the May - July time frame in CY95.

EXPERIMENT DESCRIPTION

Figure 1 shows the location of the planned experiment, on Yucca flat in hole U9cu; for comparison, the figure also displays the location on Rainier Mesa of the kiloton chemical explosion experiment that has been labeled the Nonproliferation Experiment (NPE). The symbols ELK, KNB, LAC, and MNV on the adjacent map stand for the stations of the Livermore LNN seismic network: Elko, Kanab, Landers and Mina. Figure 2 is a sketch of the (8' diameter) hole U9cu to approximate scale, and figure 3 is a radially stretched (not to scale) view of the initial condition of the hole, which is approximately 210 m deep and stemmed to a depth of 106 m. At this latter depth there is a washout to unknown distance. An 8-3/4" emplacement pipe is welded to surface casing and extends to a depth of approximately 91 m from the surface. As shown in figure 3, the pipe penetrates a 16 m gypsum aggregate plug that tops at roughly 71 m from the surface.

The first explosion will be tamped and centered at a depth of burial (DOB) of 93 m. After filling the washout with gravel or grout, a 50 kg charge of high explosive (C4) will be lowered through the emplacement pipe, as shown in figure 4. Then, a rock-matching grout will be pumped through the pipe to a level approximately 2 m above the existing plug.

Figure 5 shows the layout of the (first) decoupled explosion. A steel wiper disc,

with mounted packer at the periphery, will be lowered to a depth of 36 m via an 11.9" ID pipe. The packer will enable the wiper to seal against the surface casing so that a 12 m-thick sanded gypsum concrete or grout plug can be poured on top of the wiper. The remaining 24 m gap to the surface will then be filled in with sand. A 50 kg C4 charge will then be lowered through the pipe and suspended at a DOB of approximately 64 m. An internal packer at the bottom of the pipe will then effect a closure so that the pipe can be filled with sand to the surface. The packer is expected to be dislodged by the explosion, allowing the sand inside the pipe to fall into the cavity, which will then vent to the atmosphere; provision will also be made to forcefully vent the pipe should the explosion fail to accomplish this function. It is possible that more than one decoupled explosion (with varying charge size) will be performed in the above fashion, depending mainly on available funding.

The design of the experiments is of some interest. 50 kg explosive charges were chosen based primarily on the decoupling capabilities and desired geometry of the cavity. For $W = 50 \text{ kg}$ ($5 \times 10^{-5} \text{ kt}$), the scaled cavity radius — based on the actual radius of the cylindrical hole, r_H — is $r_H W^{-1/3} = 33 \text{ m/kt}^{1/3}$. The cavity length was selected so as to obtain an aspect ratio, $\mathcal{R} \approx 14$. With this length and the 50 kg charge, the yield-scaled radius of an equivalent volume spherical cavity is $r_V W^{-1/3} = 90 \text{ m/kt}^{1/3}$. Now, the Latter criterion for full decoupling states that the average cavity pressure should not exceed one-half of the overburden. This translates to the following expression for the required radius satisfying the Latter criterion:

$$r_L W^{-1/3} \geq \left[\frac{3(\gamma - 1)}{2\pi \rho_r g h} \right]^{1/3} \quad (1)$$

γ is the ratio of specific heats of the explosion products-air mixture, ρ_r is the rock density, g the acceleration of gravity, and h the depth of burial. For the conditions of the KUCHEN decoupled shot, $r_L W^{-1/3} \geq 81 \text{ m/kt}^{1/3}$, so that

$$r_H W^{-1/3} \leq r_L W^{-1/3} \leq r_V W^{-1/3} \quad (2)$$

In other words, the cavity size exceeds that required for full decoupling, based on an equivalent volume sphere, but is very much smaller than required by the Latter criterion if the actual radius of the cylindrical hole is used as a measure. This allows us to test the concept of using high-aspect-ratio cavities in place of spheres. If near maximum decoupling is attained (based on calculated expectations), local overdrive of the cavity walls will have been shown to have minimal effect on seismic decoupling. Any degradation, on the other hand, will be a measure of the extent to which large values of \mathcal{R} can be employed for decoupling purposes.

After the decoupling explosion(s), a final tamped explosion will be performed at the same DOB as the decoupled shot(s). Performing 2 tamped explosions allows

us to determine the effect of varying signal path to the deployed seismic instruments (the empirical Green's function). As shown in figure 6, the explosive charge will be lowered into place just as for the decoupled shot(s), but then rock-matching grout will be pumped into the former decoupling cavity up to the level of the wiper.

EXPECTED RESULTS

The seismic decoupling factor can be expressed as the product:

$$f = f_m f_G \quad (3)$$

where f_m is defined as the material decoupling factor and f_G is the geometrical decoupling factor. The material decoupling factor is actually:

$$f_m = \frac{\text{True Yield}}{W(m_b)} \quad (4)$$

where the term True Yield refers to the near-source value, normally measured by radiochemical means, and $W(m_b)$ is the yield measured by seismic means. In hard rock, with no gas porosity, $f_m \approx 1$ so that $f \approx f_G$. Figure 7 plots f_m as a function of gas porosity for 236 events at the Nevada Test Site; the data derive from Vergino and Mensing (1990). The straight line is a linear regression and shows that gas porosity can significantly affect seismic decoupling for tamped explosions. The large variance in the data reflects the fact that the explosions took place in different media, with varying strength, water saturation, depth of burial, etc.

The KUCHEN experiments will be performed in the alluvial deposits of Yucca flat, in which the gas porosity varies from approximately 10 to 20%. Preliminary estimates, therefore, are that $2 \leq f_m \leq 5$. A better estimate can be made after closer examination of the available logging data, selection of the rock-matching grout, and the firing of the first tamped explosion.

The geometric decoupling factor is also a strong function of gas porosity. Figure 8 shows the calculated variation of f_G with gas porosity, κ , for Rainier Mesa tuff. In this material, and for $0.1 \leq \kappa \leq 0.2$, f_G is seen to vary from about 10 to perhaps as low as 2. It should be pointed out, however, that the material model was synthesized based on data for the NPE (Glenn and Goldstein, 1994), and that the results are very sensitive to assumptions of how the strength and elastic properties vary with gas porosity. As with f_m , a better estimate for f_G can be made after more details are available on *in situ* material properties. At present, our best guess is that the actual attainable value of f_G will lie in the range 5-15. This leads to an expected overall seismic decoupling factor, $f = f_m f_G$, of 10-75.

CONCLUDING REMARKS

Although the KUCHEN event promises interesting results on high-aspect-ratio seismic decoupling, there are several unavoidable drawbacks associated with these experiments. Since a hard-rock site was unavailable at NTS, we are forced to deconvolve the seismic decoupling factor into components that depend on gas porosity, as well as geometry. This means that the interpreted decoupling factor will depend crucially on accurate modeling. Moreover, since hard-rock sites are of much more interest for full-scale application, we will still be missing a direct demonstration of a large \mathcal{R} system with f_m near unity. Finally, there is the question of scale effects; at 5×10^{-5} kt, KUCHEN is quite far from full-scale. These issues are not easily addressed within current budget constraints. However, we are planning a mid-scale decoupling experiment (50 ton charges) at a different (hard rock) site to follow KUCHEN in CY95. The aspect ratio for the cavity decoupled shot in this experiment will be at least 10.

All the experiments described herein will be conducted under the auspices of the Regional Monitoring Systems Division of the Department of Energy and will be jointly fielded by physicists and seismologists from both the Lawrence Livermore and Los Alamos National Laboratories.

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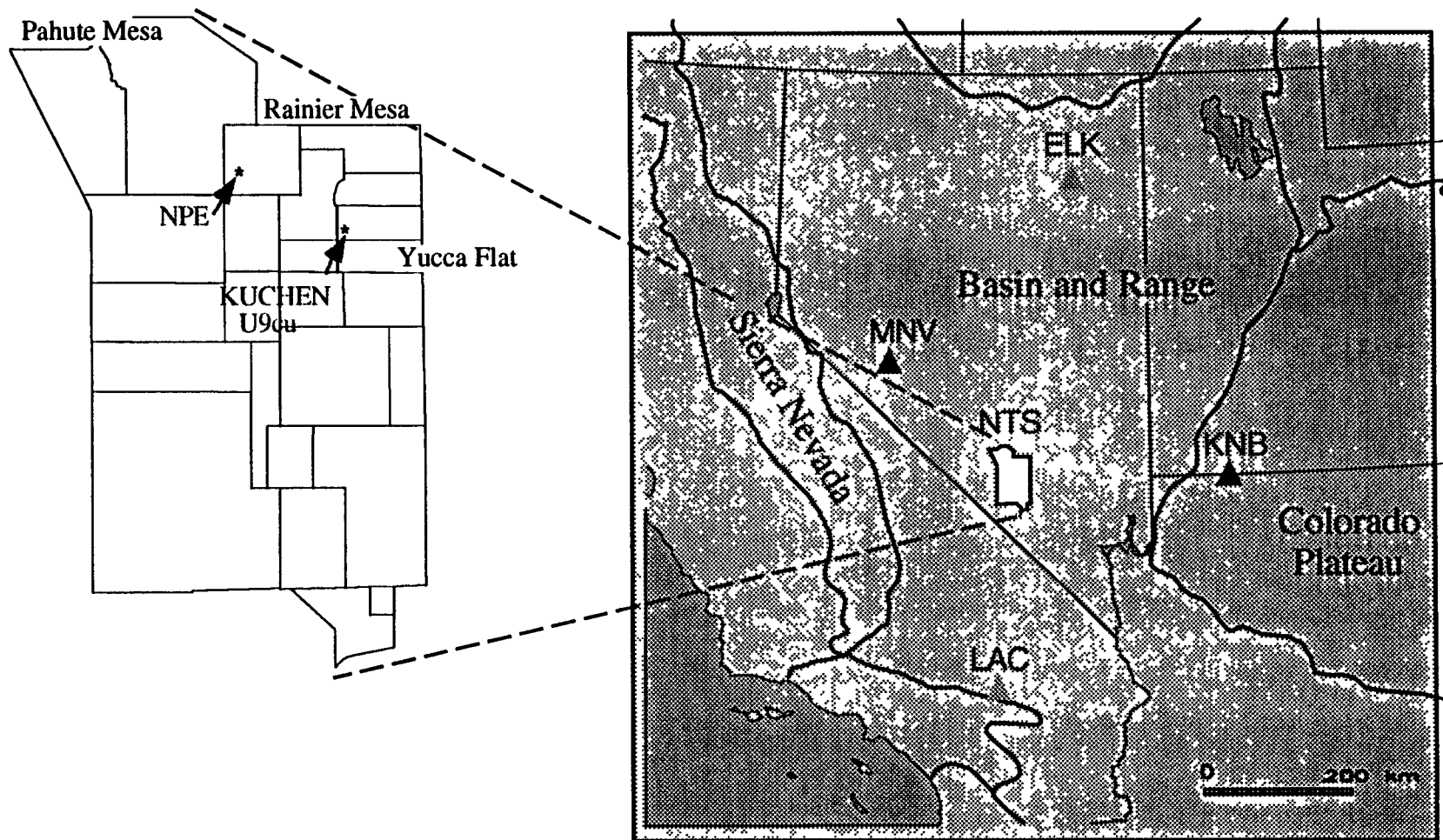


Fig. 1 Location of the planned KUCHEN event

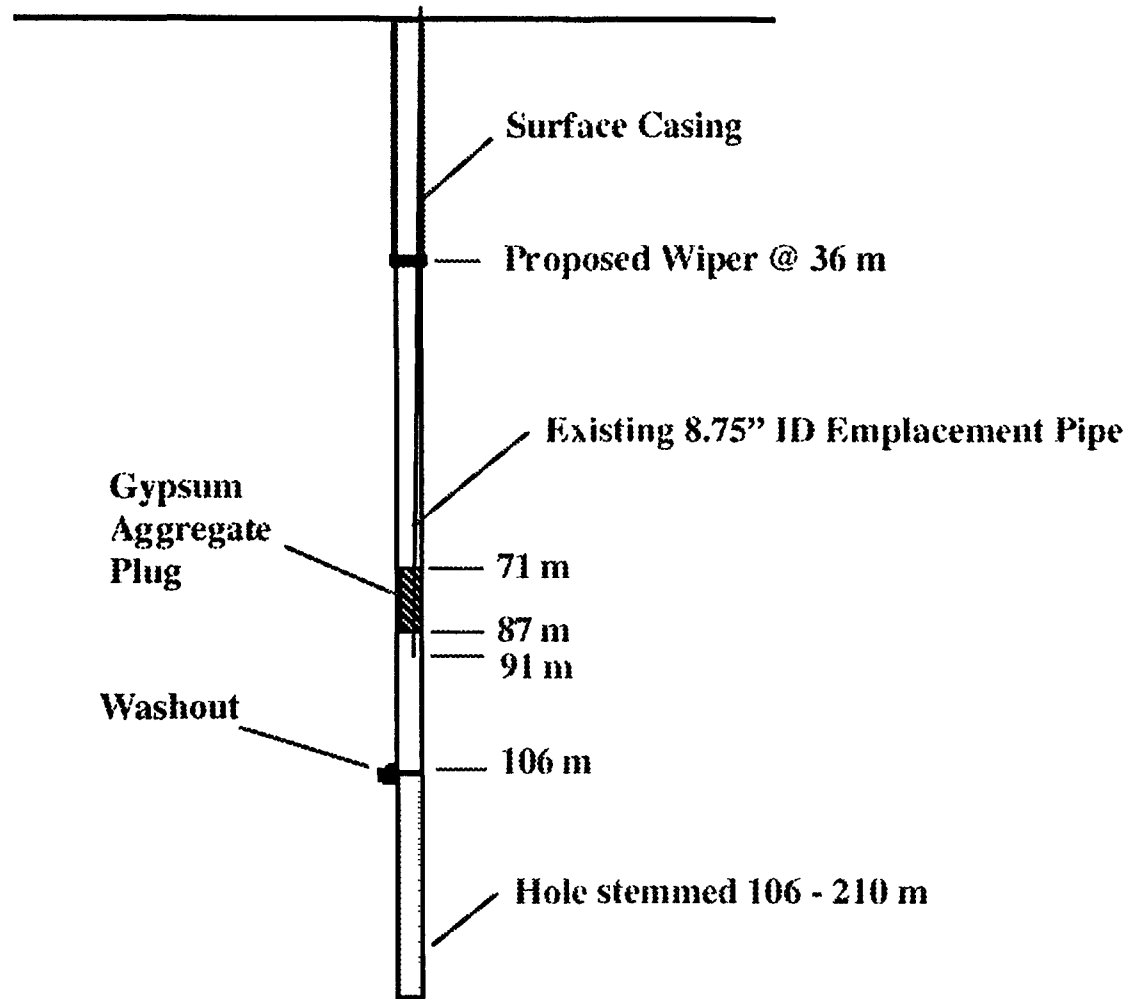


Fig. 2 Sketch of the KUCHEN hole (U9cu) to a approximate scale

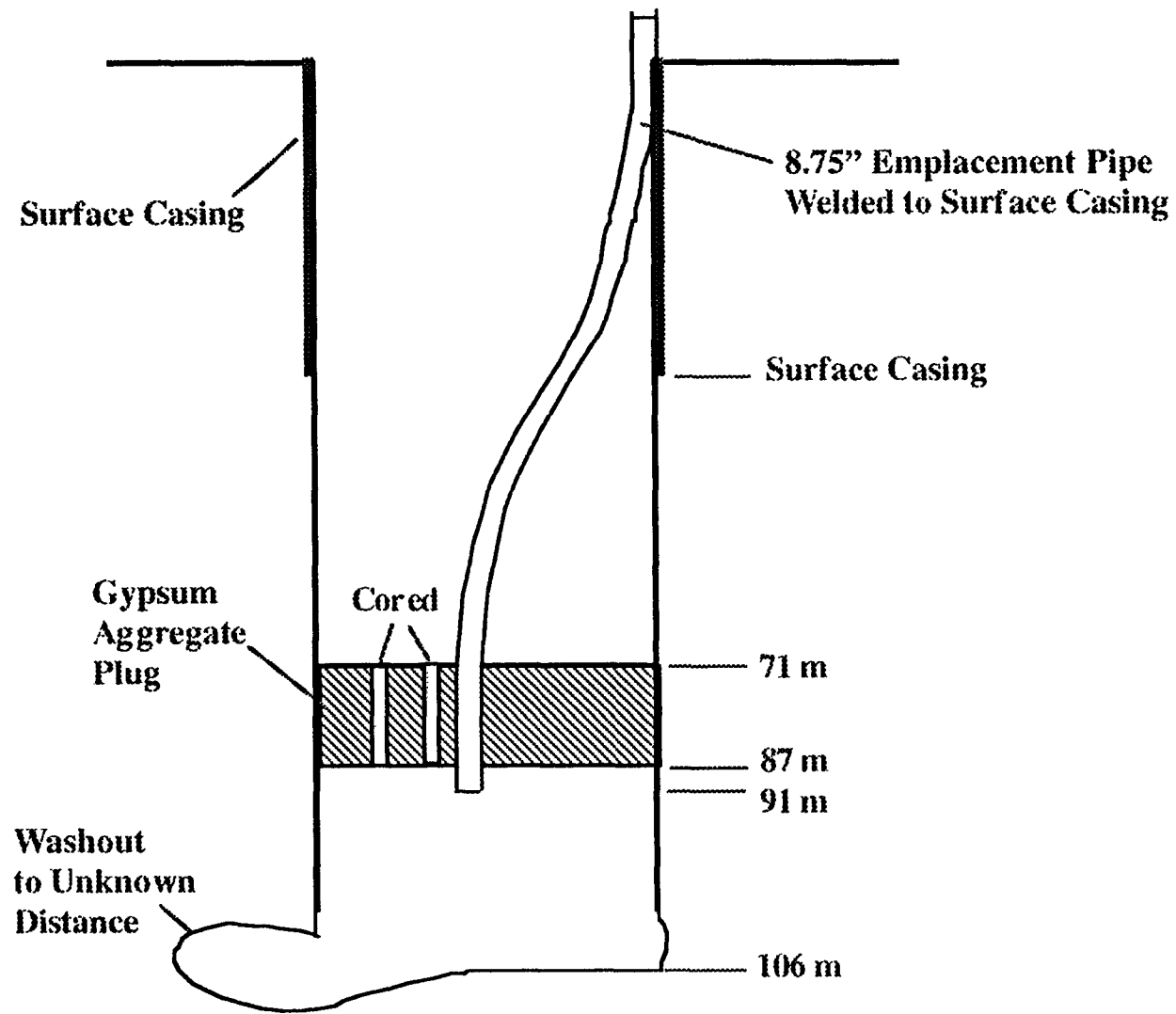


Fig. 3 Sketch of initial condition of Hole U9cu - radially stretched (not to scale)

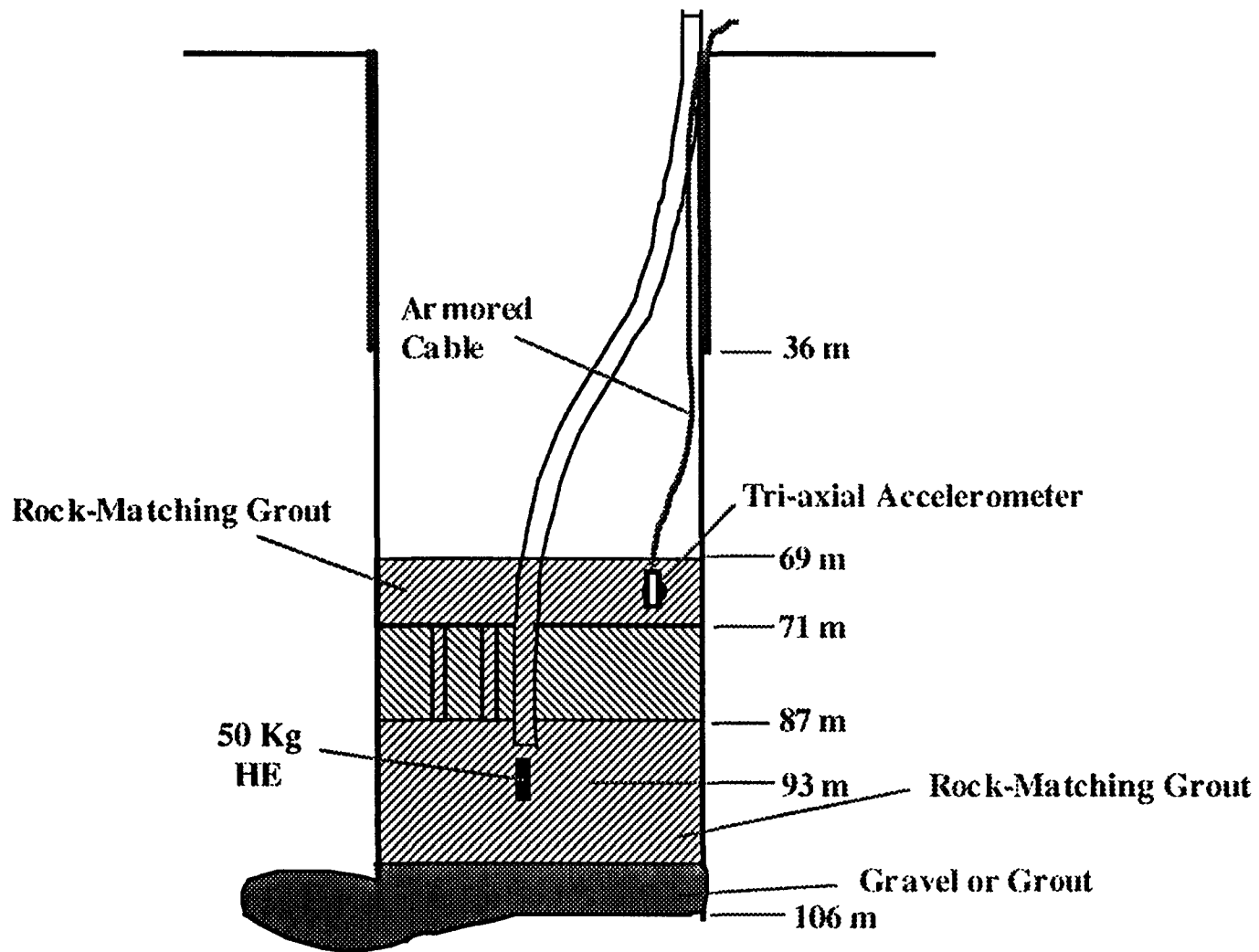


Fig. 4 Layout of first tamped explosion

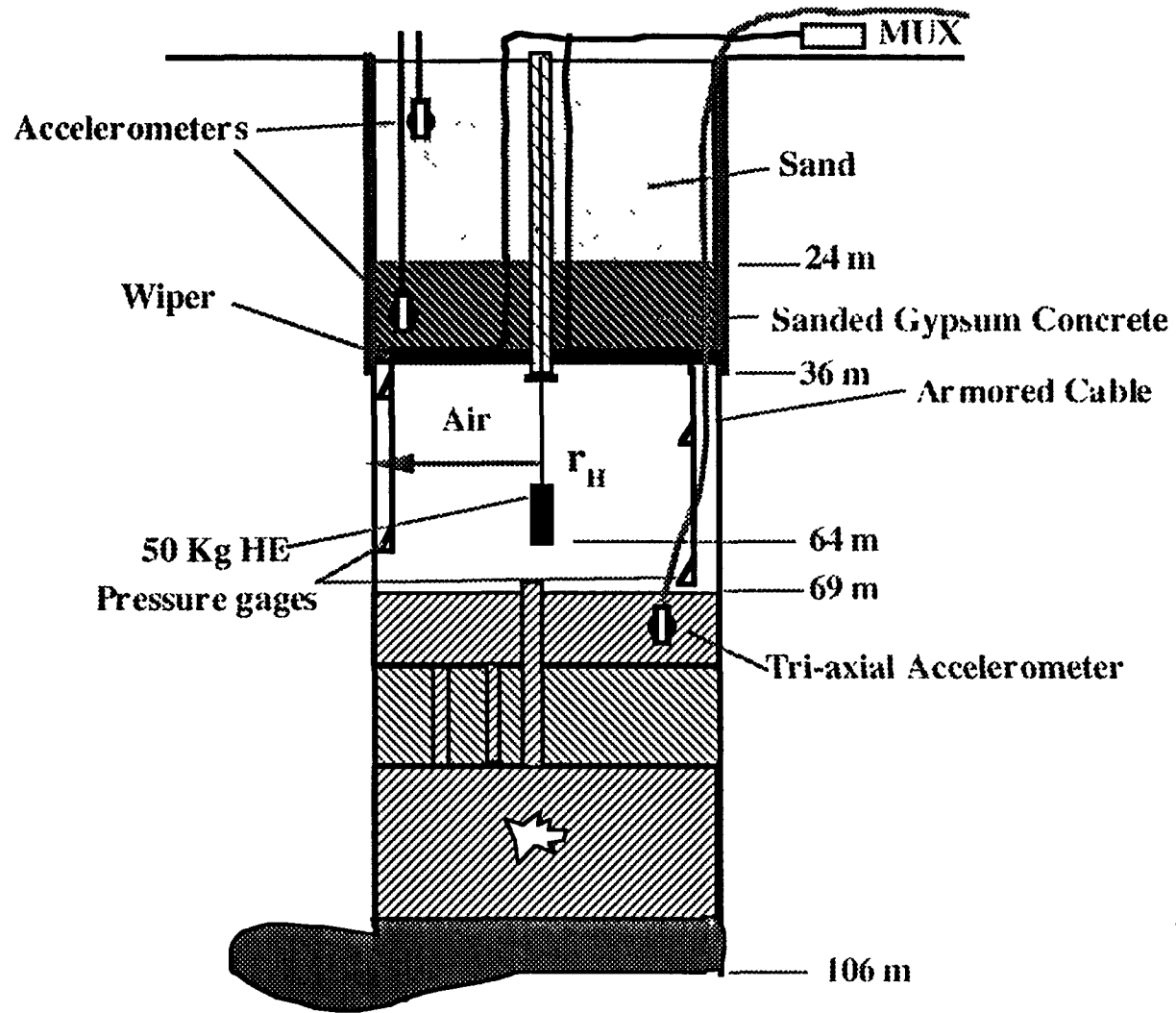


Fig. 5 Layout of (first) decoupled explosion

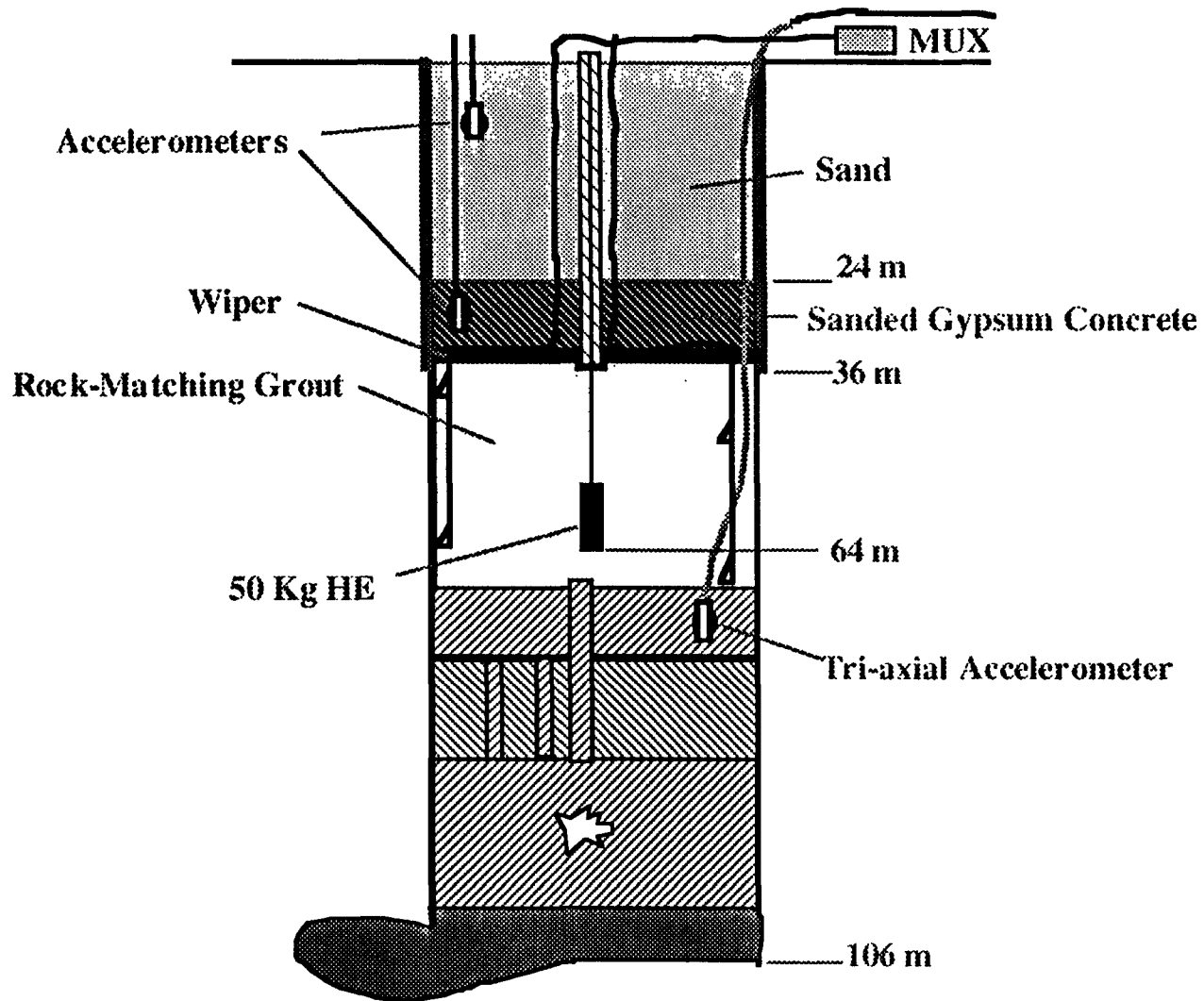


Fig. 6 Layout of final tamped explosion

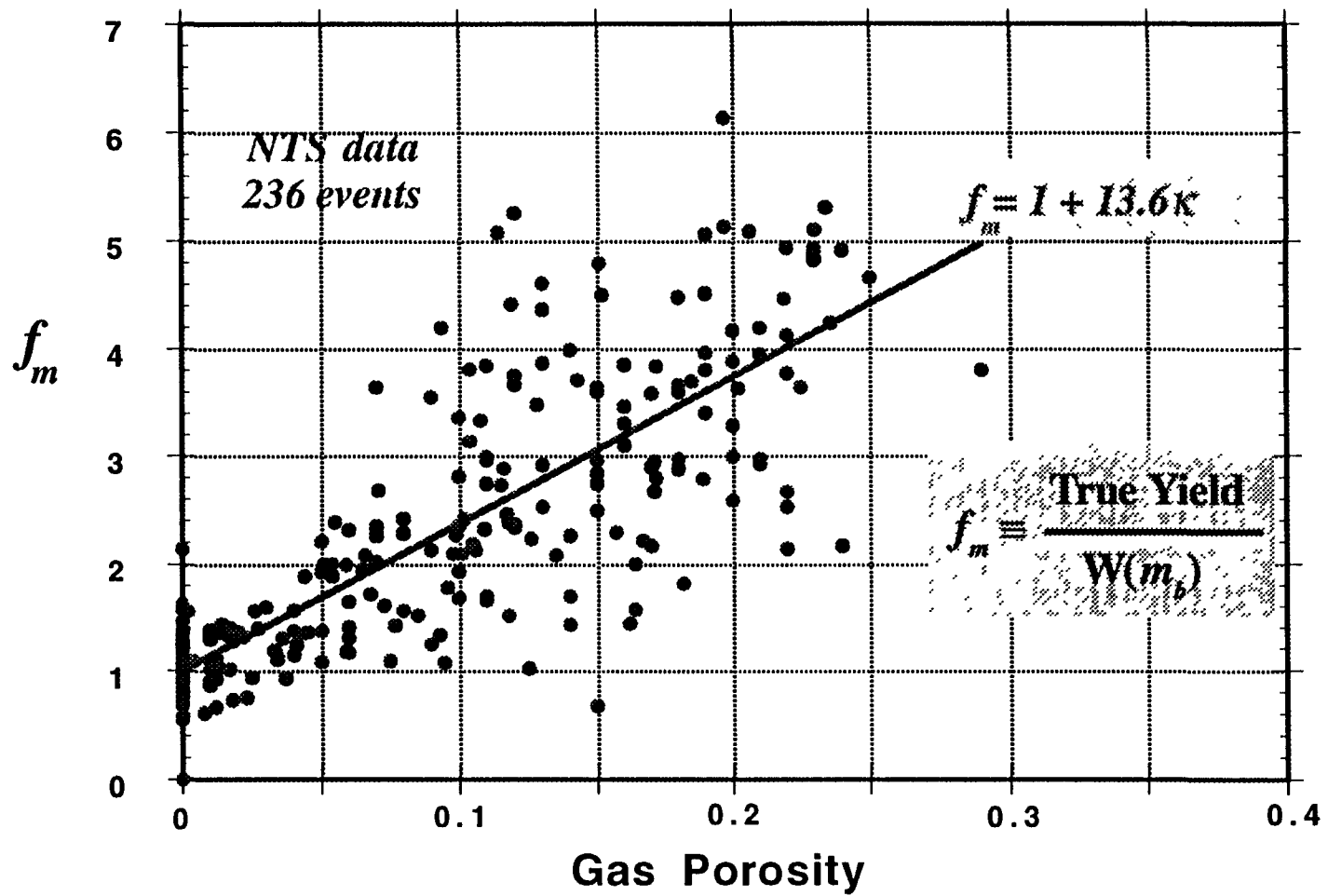


Fig. 7 Material decoupling factor as a function of gas porosity - data from *Vergino & Mensing (1990)*

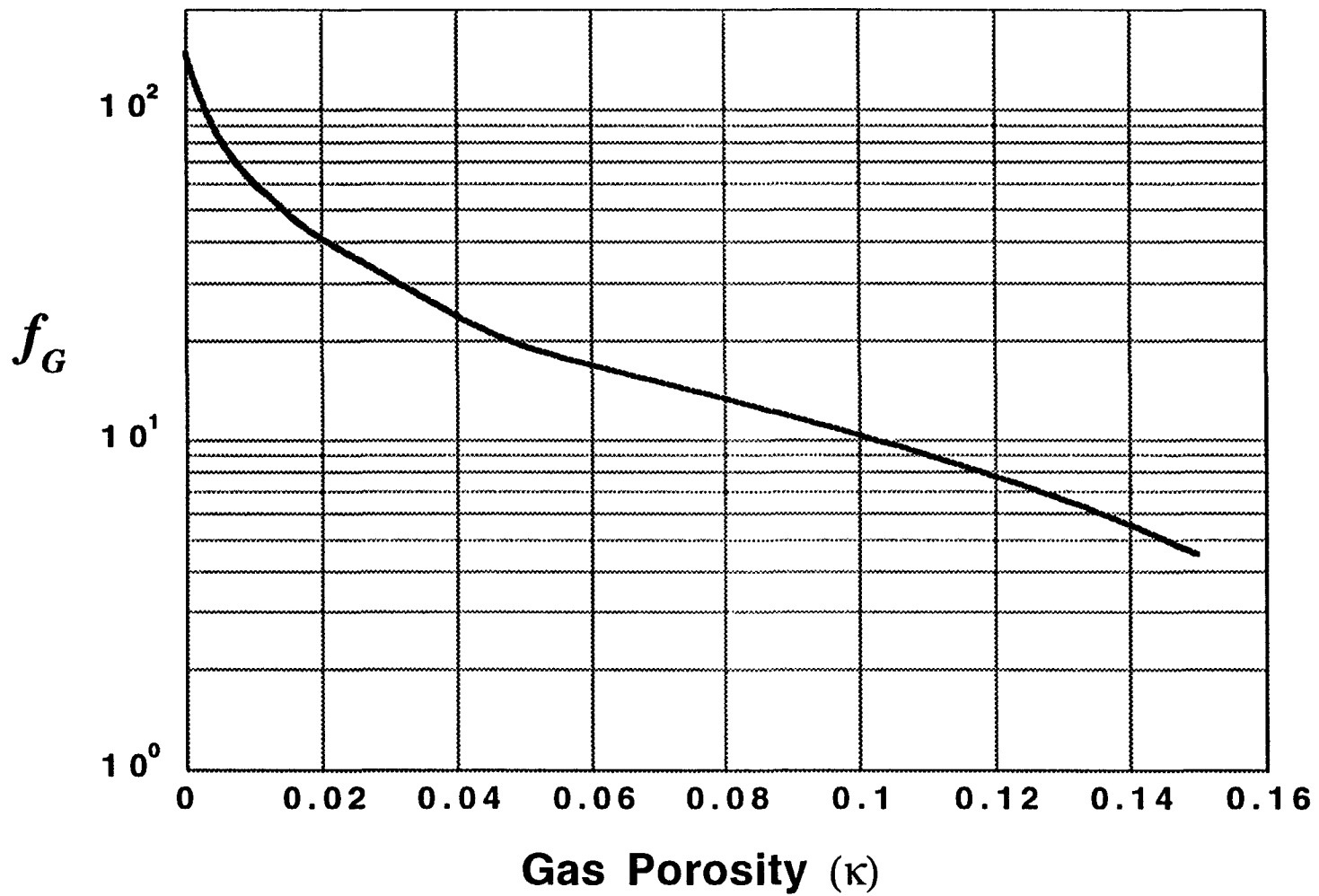


Fig. 8 Calculated geometric decoupling factor as a function of gas porosity for Rainier Tuff