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Aerosolverhaltensrechnungen mit dem Computercode NAUA-Mod5M

Zusammenfassung

Der vorliegende Bericht beschreibt Rechnungen zum Aerosolverhalten im Rahmen der europäischen Studie SEAFP (Safety and Environmental Assessment of Fusion Power). Mit Hilfe des Computerprogramms NAUA-Mod5M wurde für eine Reihe von verschiedenen angenommenen Unfallszenarien ermittelt, inwieweit das Containmentsystem des geplanten Fusionsreaktors in der Lage ist, aerosolförmige Aktivität zurückzuhalten. Das Programm NAUA-Mod5 kann das Aerosolverhalten in einer beliebigen Mehrraumgeometrie simulieren und wurde ursprünglich für Anwendungen auf Unfälle in LWRs entwickelt.

Insgesamt wurden sechs verschiedene Szenarien analysiert, zwei für den heliumgekühlten RPM (Reference Plant Model) und vier für den wassergekühlten APM (Alternative Plant Model). Die Unterschiede liegen dabei vor allem bei der berücksichtigten primären Aerosolquelle, ob etwa das Material der ersten Wand Be oder W ist oder ob ein Divertorkühlkreislauf oder ein Primärkühlkreislauf versagt. Die Ergebnisse zeigen wie bereits bei früheren Rechnungen den Erfolg des Konzepts der schrittweisen Barrieren des geplanten Containmentsystems.

Abstract

This report presents the aerosol behaviour calculations within the framework of SEAFP task A8 "Radioactivity confinement analysis". The retention capability for the aerosol-type activity of the containment has been evaluated for a number of different accident scenarios with the code NAUA-Mod5M. This code is designed to simulate the aerosol behaviour for an arbitrary multi-compartment containment originally for applications in LWR containments after severe accidents.

Altogether six different scenarios have been evaluated, two for the He-cooled RPM and four for the watercooled APM. These scenarios differ mainly in the primary source taken into account, if e.g. the armour of the first wall consists of Be or W or if the divertor cooling loop or a primary cooling loop fails. The results show the positive influence of the system of step by step barriers already proved to be successful for other applications.

1. Introduction

The task "A8" has been defined as "Radioactivity confinement analysis". The main carriers of radioactivity in the case of a fusion device are:

- Tritium in the form of HTO (main component) and T_2 or HT
- Gases, e.g. He, N, C (assumed as CO or CO_2)
- Aerosol particles, most other nuclides

Under most circumstances (superheated conditions of the containment atmosphere) water will be gaseous and has, therefore, treated accordingly. Possible sinks for water vapour are cold surfaces where condensation may occur. To specify the possible retention capacity of the containment for tritiated water a careful thermohydraulic analysis is required. In some cases water can also be connected to the aerosol if either soluble and hydrophilic particles are present or the water vapour is supersaturated. Since both conditions are not expected to hold in the case of the containment of the planned fusion device, all tritium should be assumed to be gaseous.

In the analysis presented in this report the transport and retention of the aerosol particles are calculated using the code NAUA-Mod5M /1/. As input for the calculations thermohydraulic data from WAVCO-calculations (Siemens/KWU) /4/ and aerosol source term data for the long-time source from APMOB-calculations and for the initial instantaneous source from activation calculations (UKAEA, Culham) /5,6/ have been used. Comparative calculations on the basis of thermohydraulic results from the COPTA-code (Studsvik EcoSafe) /7/ were originally planned but could not be carried out as these data cover only the first 12 h of the accident. This is not sufficient for aerosol behaviour calculations.

2. The Code NAUA-Mod5M

NAUA-Mod5M is a strictly mechanistic code to calculate the aerosol behaviour in containment systems with arbitrary nodalization. The term "mechanistic" means that no restrictions for the shape of the aerosol size distribution e.g. log-normal or any other distribution have to be made but the general dynamic equation of aerosols (GDE) is directly solved using a discretization scheme for the aerosol size. Due to the mixed linear and non-linear character of the resulting differential equations they have to be solved by numerical methods using a standard integration method.

The code takes into account coagulation between particles leading to particle size growth, deposition due to gravitional sedimentation, Brownian diffusion and diffusiopheresis. The transport of the particles between the different compartments of the containment system is calculated on the basis of flow velocities provided by a suitable thermohydraulic code. The environment is treated as one compartment but no flow reversal will be considered and no aerosol behaviour is calculated in the environment. The flow of particles into the environment provides the source term for the calculations of the atmospheric distribution and the subsequent radiological consequences.

A detailed description of the physics of the aerosol model and of the code can be found in /1,2,3/.

3. Accident sequences

3.1 Reference Plant Model (RPM)

It is assumed that one coolant loops breaks within the vacuum vessel (In-vessel LOCA). Due to the fact that the temperature rise of the blanket will be quite small the only aerosol source terms are erosion dust in the vacuum vessel produced during normal operation and the activation product in the coolant including material resuspended from the inside of the cooling pipes after depressurization. As parameter variations Be as well as W armour is considered. The total concentration of activation products in the He-coolant is 21.3 $\mu g/m^3$ but 15.8 $\mu g/m^3$ consist of Nitrogen. Therefore, only the difference (5.5 $\mu g/m^3$) can be assumed to form solid material. As one coolant loop contains 240 m^3, the total mass of aerosol particles from this source is 1.32 mg.
The amount of erosion dust mobilized was estimated to be 700 g in the case of the Be-armour and 6000 g in the case of W-armour. The aerosol source term is therefore dominated by the erosion dust. Since the size of the primary particles is not known, the mean geometric radius of the size distribution was assumed to be 0.1 µm with a standard deviation of 2 (log-normal initial distribution). These data are quite conservative values due to the fact that most particles are formed by fragmentation processes yielding usually larger sizes.

3.2 Alternative Plant Model (APM)

For the water cooled APM two sequences were considered, break of one divertor cooling loop or break of one primary cooling loop. In addition to the two aerosol sources mentioned above a long term source of activation product in the structural materials and the breeders has to be taken into account due to a slow increase of the temperature and subsequent vapourization of some nuclides. The combination of these sequences with the two possible materials for the armour Be (the standard for the APM) and W yields all together four different cases which had to be examined:
1) Be divertor armour/Cu divertor structure/Be erosion dust/activation products from 1 divertor cooling loop
2) W divertor armour/Cu divertor structure/W erosion dust/activation products from 1 divertor cooling loop
3) Be first wall armour/first wall LA12 material/Be erosion dust/activation products from 1 primary cooling loop
4) W first wall armour/first wall LA12 material/W erosion dust/activation products from 1 primary cooling loop

The amount of erosion dust is very close to the values for the RPM about 700 g for the Be-dust and 6000 g for the W-dust. But the coolant activation products again together with material from the inside of the pipes are now the main component of the aerosol source. For the divertor cooling loop the concentration amounts to approximately 3330 g/m^3 and for the primary cooling loop to 94694 g/m^3. Taking into account the volume of the loops (23 m^3 for the divertor and 45 m^3 for the primary loop) the total mass of this aerosol source will be 76.6 kg in the 1st case and 4261 kg in the 2nd case. Due to the fact that the flow out of the vacuum vessel stops at about 30000 s and no further transport of the particles into the containment system takes place the coolant activation products are the dominant source term whereas the long term source has only limited influence on the source term to the environment.

4 Results

4.1 General

The main objective of the NAUA-calculations consists in providing a source term for the atmospheric dispersion calculations. Therefore, the transport over barriers in the containment system affecting directly the transport into the environment is of special importance. The simplified structure of the containment system was defined by the WAVCO-calculations and can be seen in the Figs. 3.3 (APM) and 3.4 (RPM) of /4/. According to the layout of the containment and the possible active accident management measures the transport over the 2nd (from the expansion volume to the confinement) and the 3rd (from the confinement to the environment) have to be considered. The reason is that two paths of the activity to the environment are possible either directly from the confinement by a high volume blower (via a stack and a filter system) or from in the confinement through leakages if the confinements is slightly overpressurized. In the first case it is assumed that large openings to the environment stay open during an accident and that the material transported over the 2nd barrier will more or less completely flow into the ventilation system. The retention within the confinement is negligible in this case. In the second and the third case - a case where containment closing works in contrast to case one and underpressure to the environment is kept by a ventilation system - the deposition of the particles in the confinement plays an important role. The 2nd and 3rd case are very similar, most particles transported over the 2nd barrier are retained in the confinement and only the transport rate through the 3rd barrier increases by a factor in the order of 2 to 10. The two cases differ in the fact that in the 3rd case the flow is filtered and released via a stack.

4.2 RPM

As mentioned above erosion dust is the main primary source term for the RPM. The activation of the first wall and other structural components is too low so that the temperature rise is too small to vapourize any compounds. The transport of the airborne material through the containment system is shown in the Figs. 1 and 2 showing the airborne mass in the different compartments as a function of the time. Due to the delayed transport of the particles the mass in the confinement increases up to about 50 h and decreases slowly afterwards by the natural deposition processes including the leakage into the environment. The retention capability of the confinement can also be seen if the transport rates over the 2nd and 3rd barrier are compared (Figs. 3 and 4). The total mass of aerosol deposited in the confinement is 38 g in the case of the Be-armour and 319 g in the case of W-armour. If these numbers are compared to the accumulated total leakages into the environment 1 g and 7 g respectively, they show clearly the positive effect of the confinement to reduce the overall source term.

4.3 APM

Unlike the RPM the coolant activation products are the most important source term. In addition to the two instantaneous sources a long term source term from the activation of the first wall has to be considered. But its influence on the radiological source term is only small as already mentioned above. The Figs. 5 to 8 show the transport of the aerosol particles through the containment system. The increase of the airborne mass in the vacuum vessel after 10^5 s is caused by the long term source and the lack of a flow transporting the particles into the other compartments. This can also be seen in Figs. 9 to 12 showing the transport over the different barriers for the case of slight overpressurization (2nd case). The total mass of aerosol transported across the 2nd barrier and the 3rd barrier is:

case	2nd barrier	3rd barrier
Be-dust/div. str.	7.3 kg	106 g
W-dust/div. str.	7.7 kg	110 g
Be-dust/prim. cool l.	116.5 kg	364 g
W-dust/prim. cool. l.	116.7 kg	364 g

The numbers show the effect of the non-linear behaviour of the aerosols. The ratio between the masses drops from approximately 50 for the primary source term to 15 for the transport over the 2nd barrier to about 3 for the transport over the 3rd barrier. The same will, off course, not hold for any gases (water vapour, noble gases, carbon oxides etc.). Again as in the case of the RPM the retention capability of the confinement for the aerosol type activity could clearly be shown.

5 Conclusions

Calculations with the code NAUA-Mod5M were carried out to simulate the transport of the aerosol-type activity through the containment system of the planned fusion reactor. The results show the high retention capability of the containment. If the integrity of the confinement can be maintained and assuming the normal leakages of the building the overall retention factor varies between 760 and 12000 depending on the case. The smaller numbers apply for low initial aerosol concentrations and the higher numbers for high initial concentrations.

6 References

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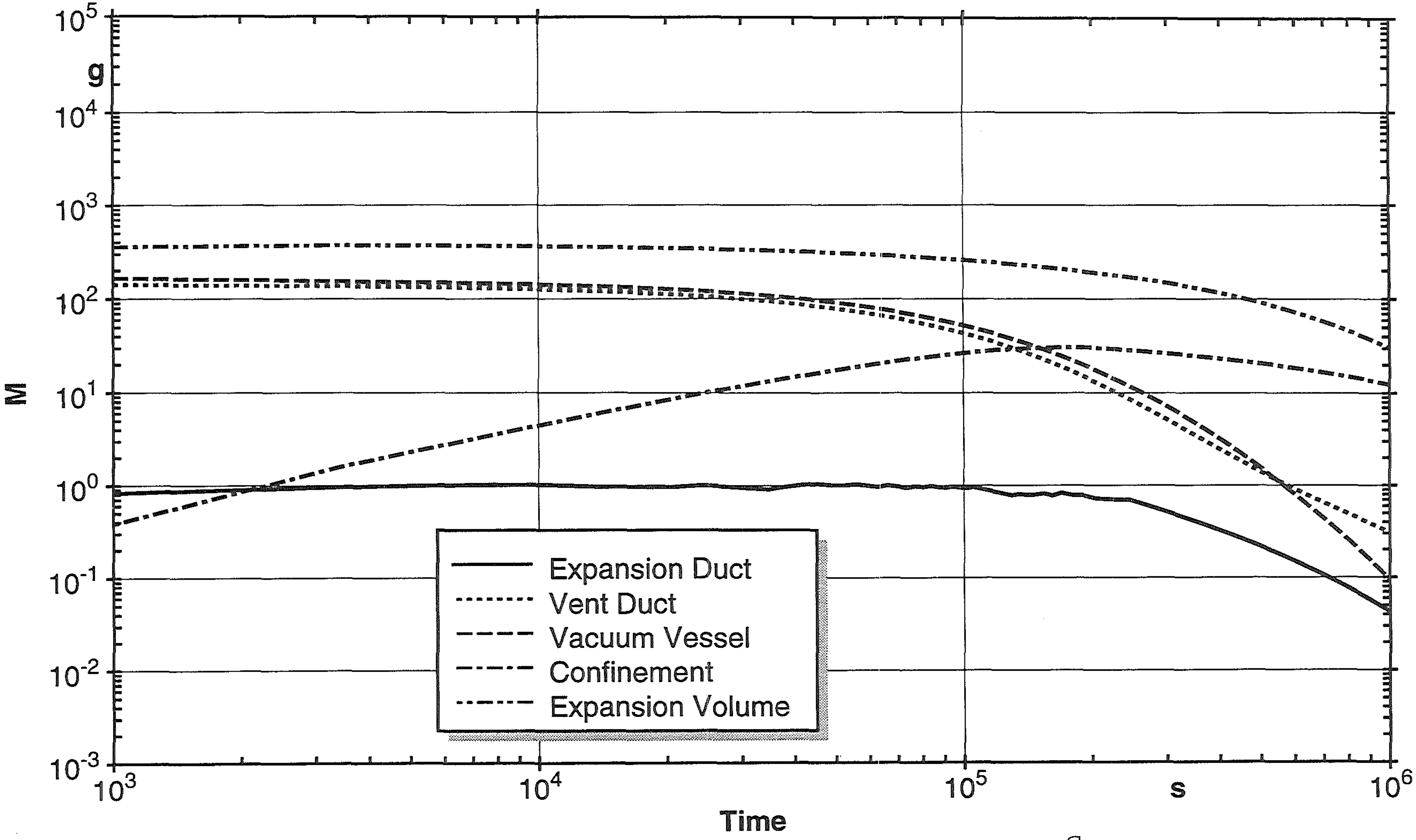
/3/ H. Bunz, M. Koyro, W. Schöck (1987), KfK 4278
/4/ K.F. Freudenstein (1994), Rep. No. KWU/NDS3/94/E2022
/5/ C.B.A. Forty (1994), A10 Task Report R-A10/4-Rev. 0
/6/ C.B.A. Forty, P.J. Karditsas (1994), A10 Task Reports R-A10/5-Rev. 0
/7/ R. Blomquist, K. Shen (1994), A8 Task Report R-A8.1 Rev. 2

Remark: Ref. 4 to 7 will be published as parts of the report "Safety and Environmental Assessment of Fusion Power"

7 Figures

Fig. 1: Airborne mass for the RPM with Be-armour
Fig. 2: Airborne mass for the RPM with W-armour
Fig. 3: Transport over the different containment barriers for the RPM with Be-armour
Fig. 4: Transport over the different containment barriers for the RPM with W-armour
Fig. 5: Airborne mass for the APM with Be-armour, failure of one divertor loop
Fig. 6: Airborne mass for the APM with W-armour, failure of one divertor loop
Fig. 7: Airborne mass for the APM with Be-armour, failure of one primary cooling loop
Fig. 8: Airborne mass for the APM with W-armour, failure of one primary cooling loop
Fig. 9: Transport over the different containment barriers for the APM with Be-armour, failure of one divertor loop
Fig. 10: Transport over the different containment barriers for the APM with W-armour, failure of one divertor loop
Fig. 11: Transport over the different containment barriers for the APM with Be-armour, failure of one primary cooling loop
Fig. 12: Transport over the different containment barriers for the APM with W-armour, failure of one primary cooling loop



KfK IMK

Fig. 1 RPM : Airborne Mass

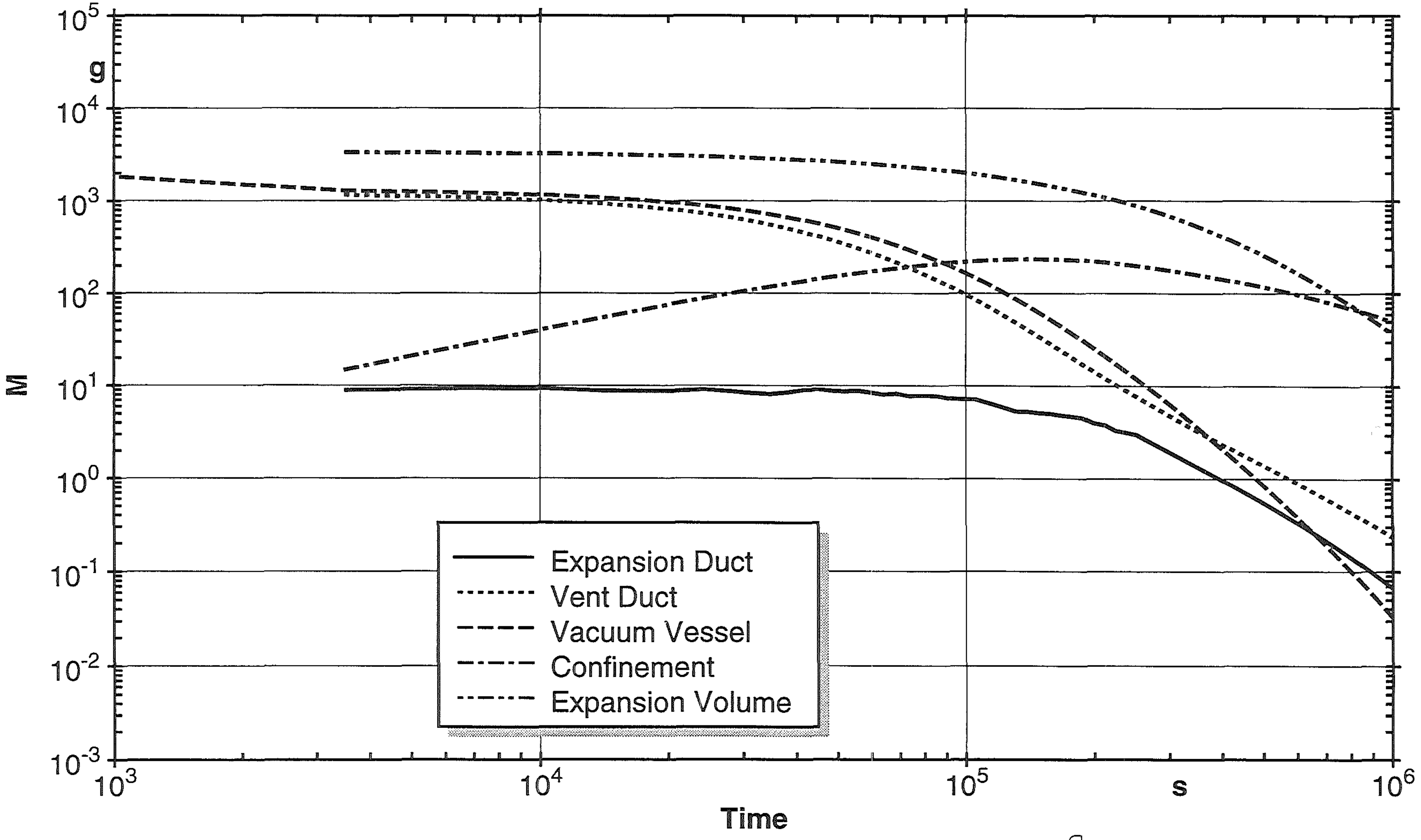


Fig. 2 **RPM : Airborne Mass**

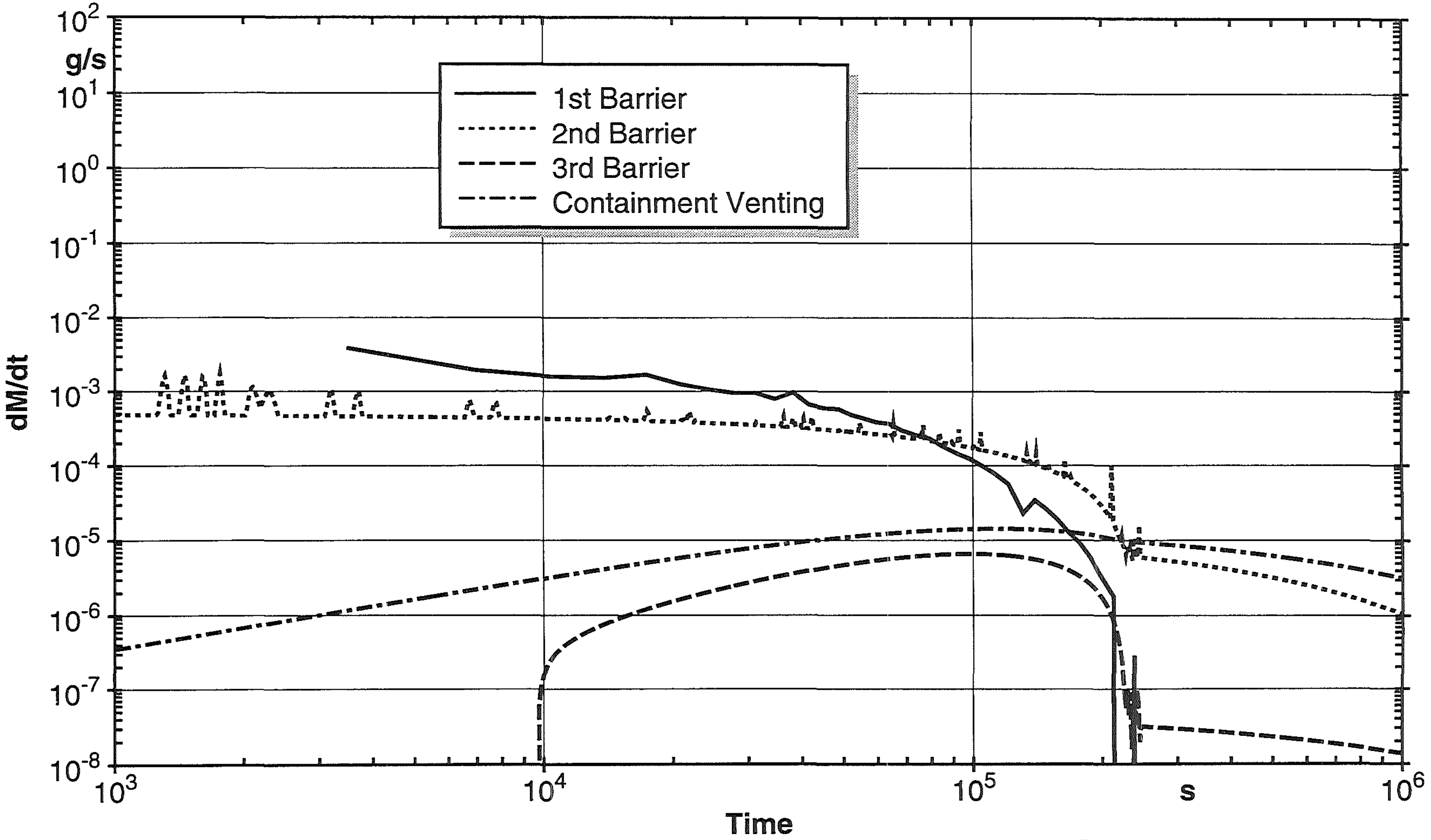


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Fig. 3 RPM : Transport over Barriers

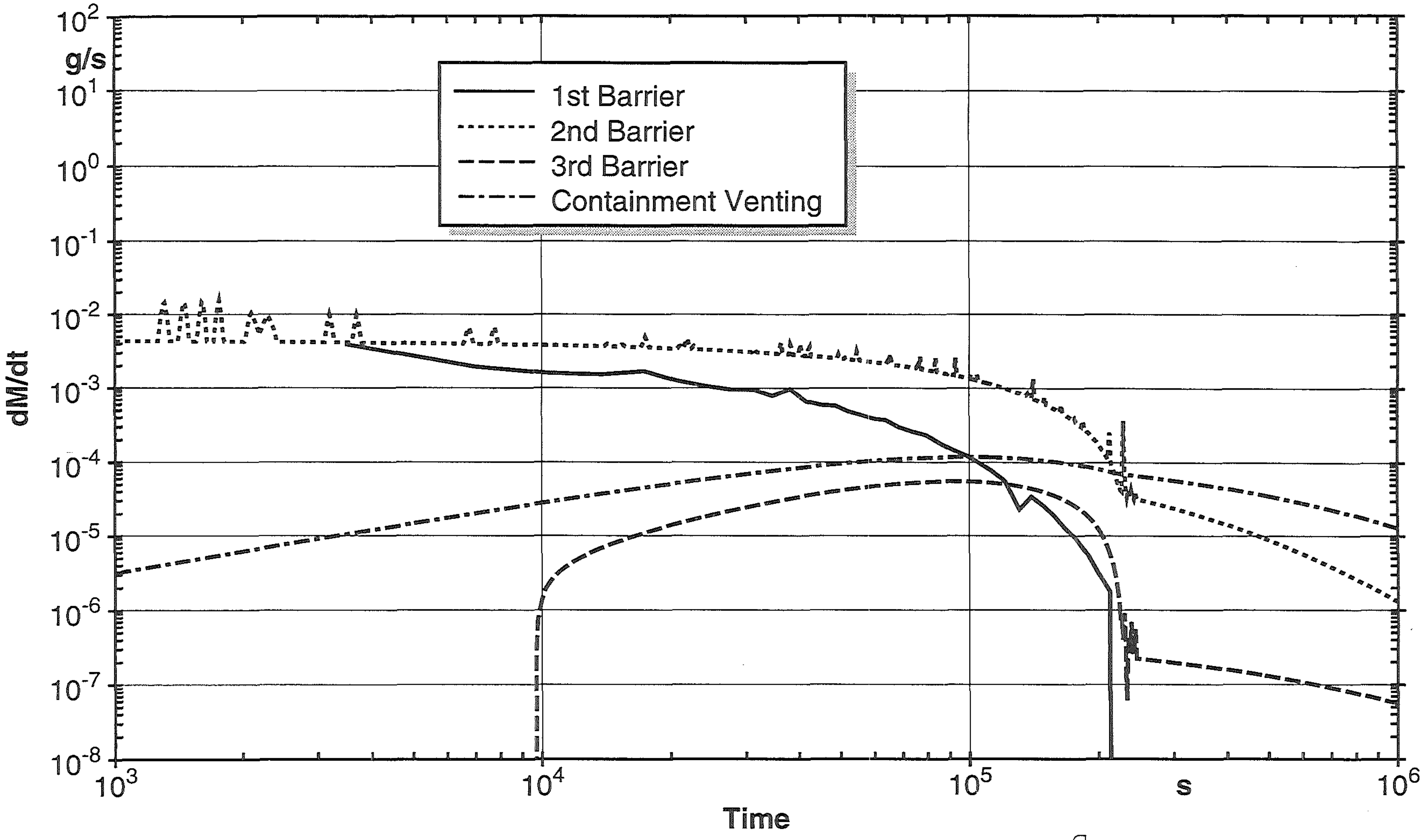

Fig. 4 RPM : Transport over Barriers

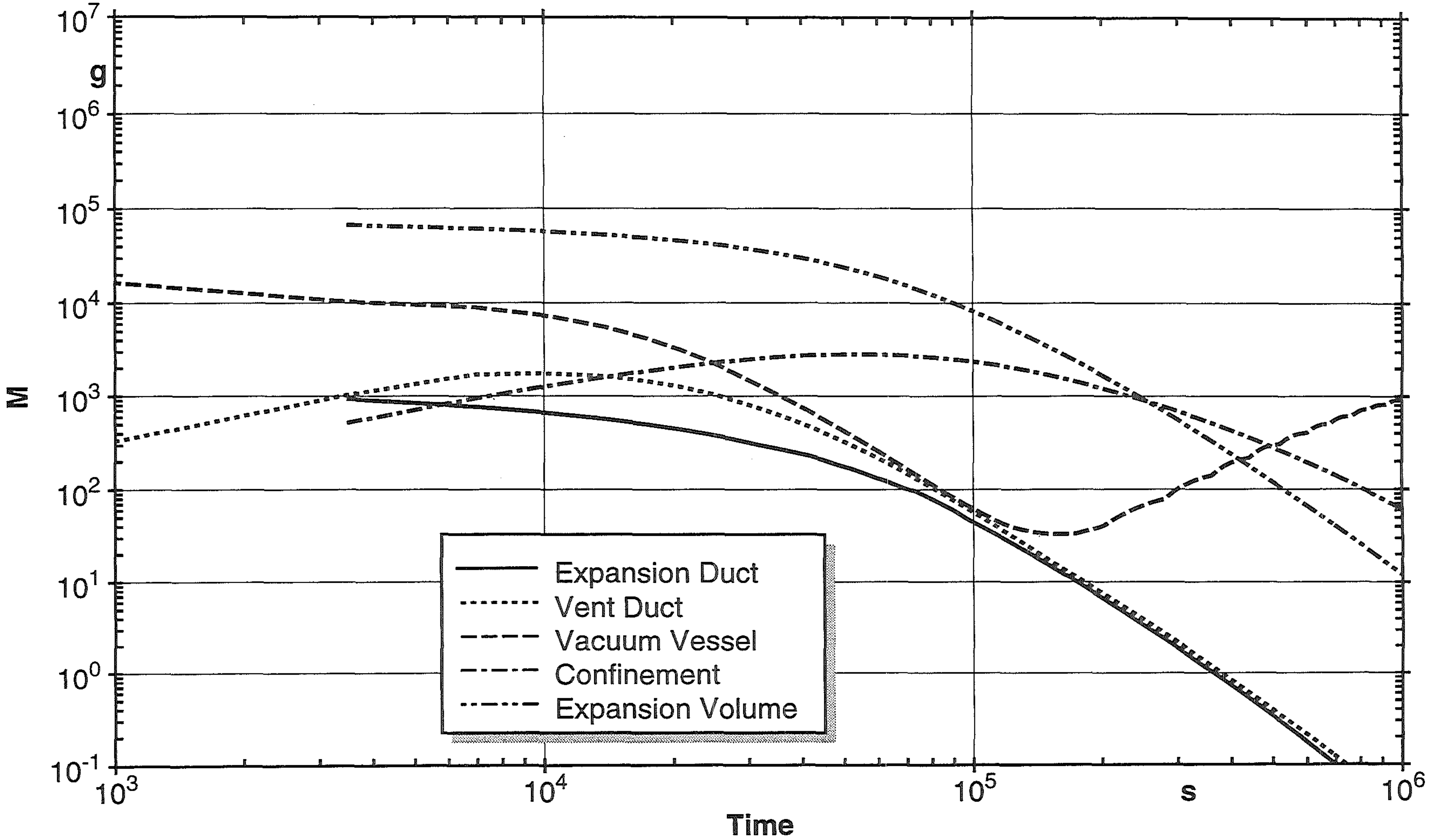

Fig. 5

APM : Airborne Mass

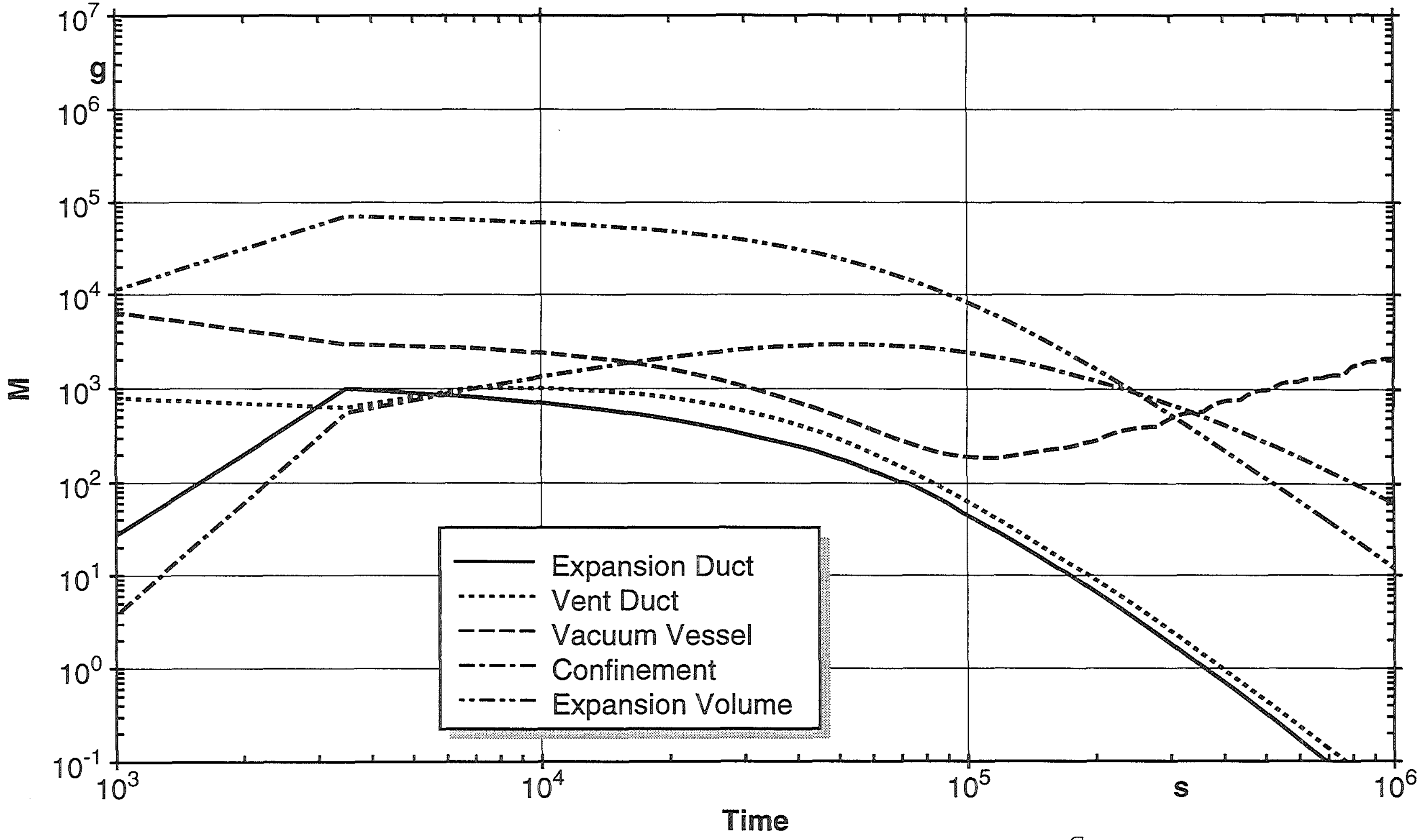

Fig. 6 **APM : Airborne Mass**

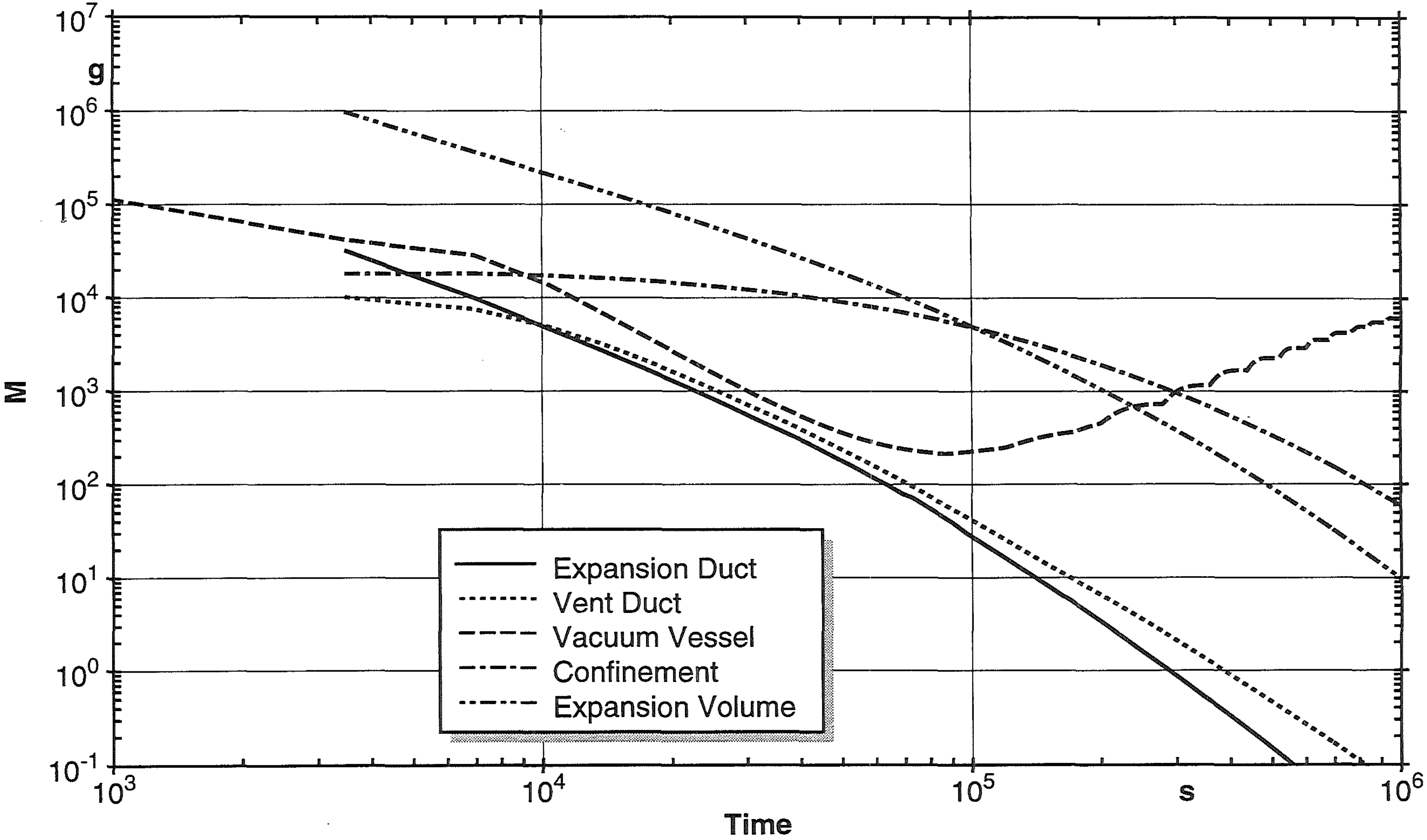

Fig. 7 **APM : Airborne Mass**

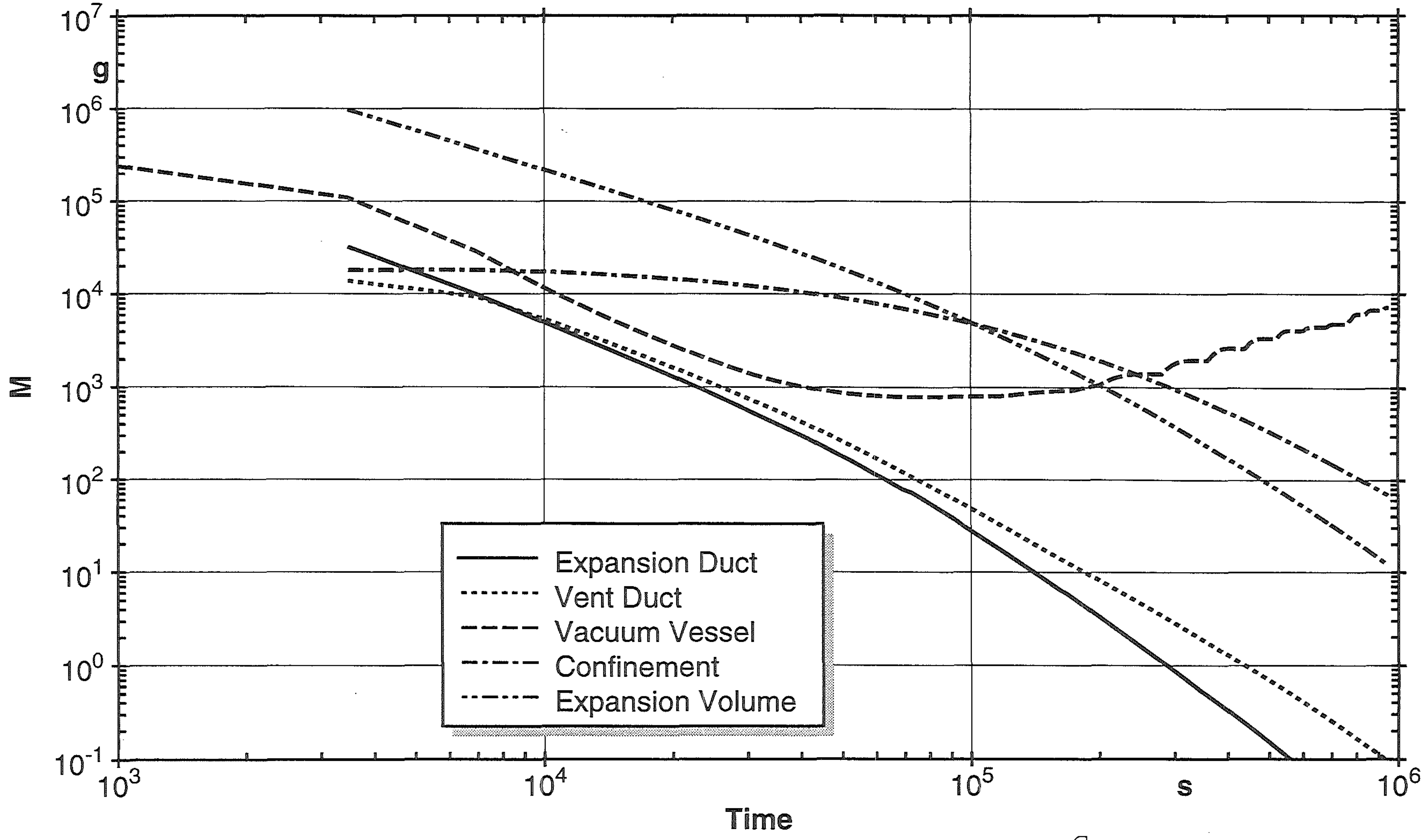

Fig. 8

APM : Airborne Mass

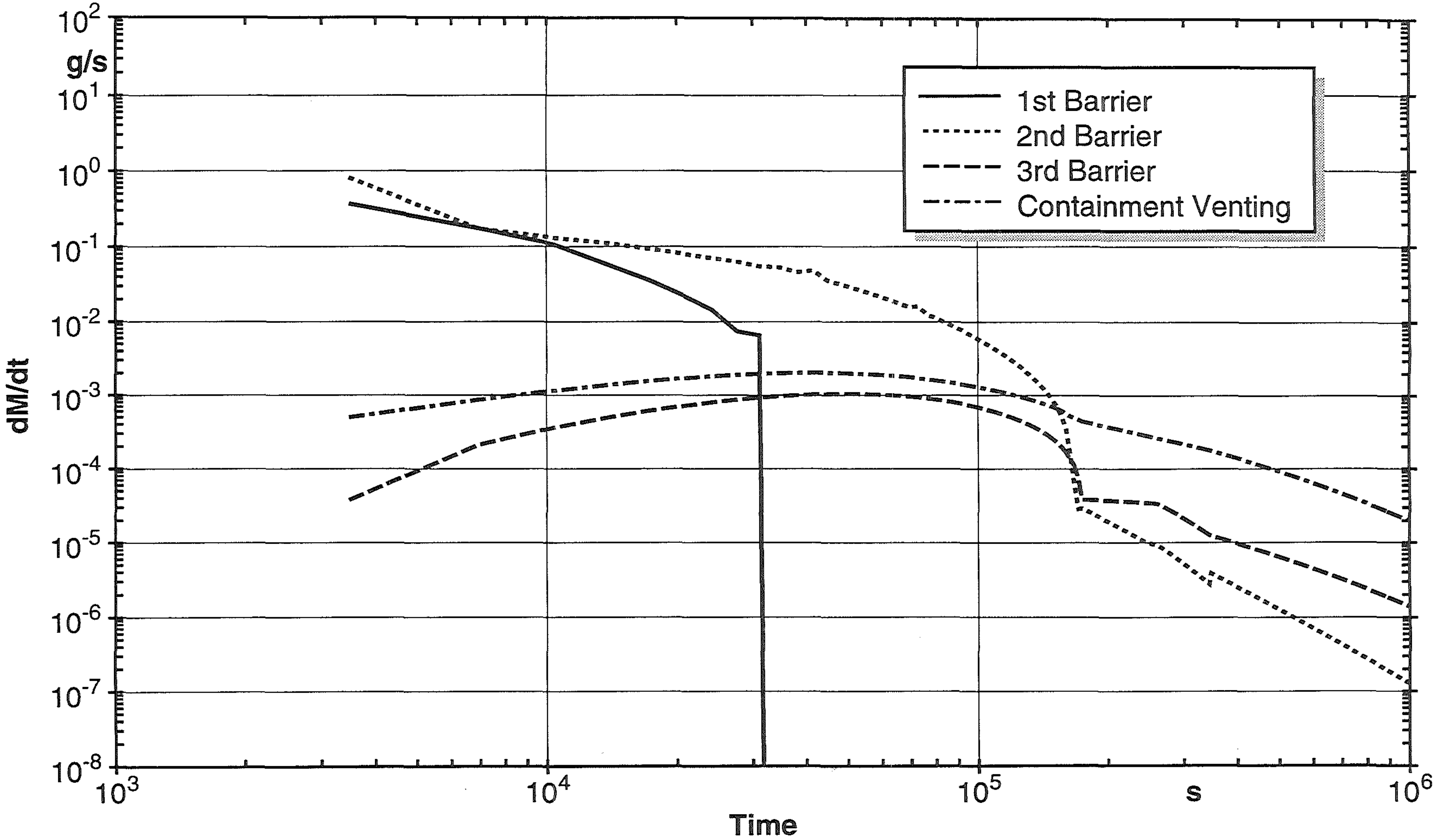

Fig. 9 APM : Transport over Barriers

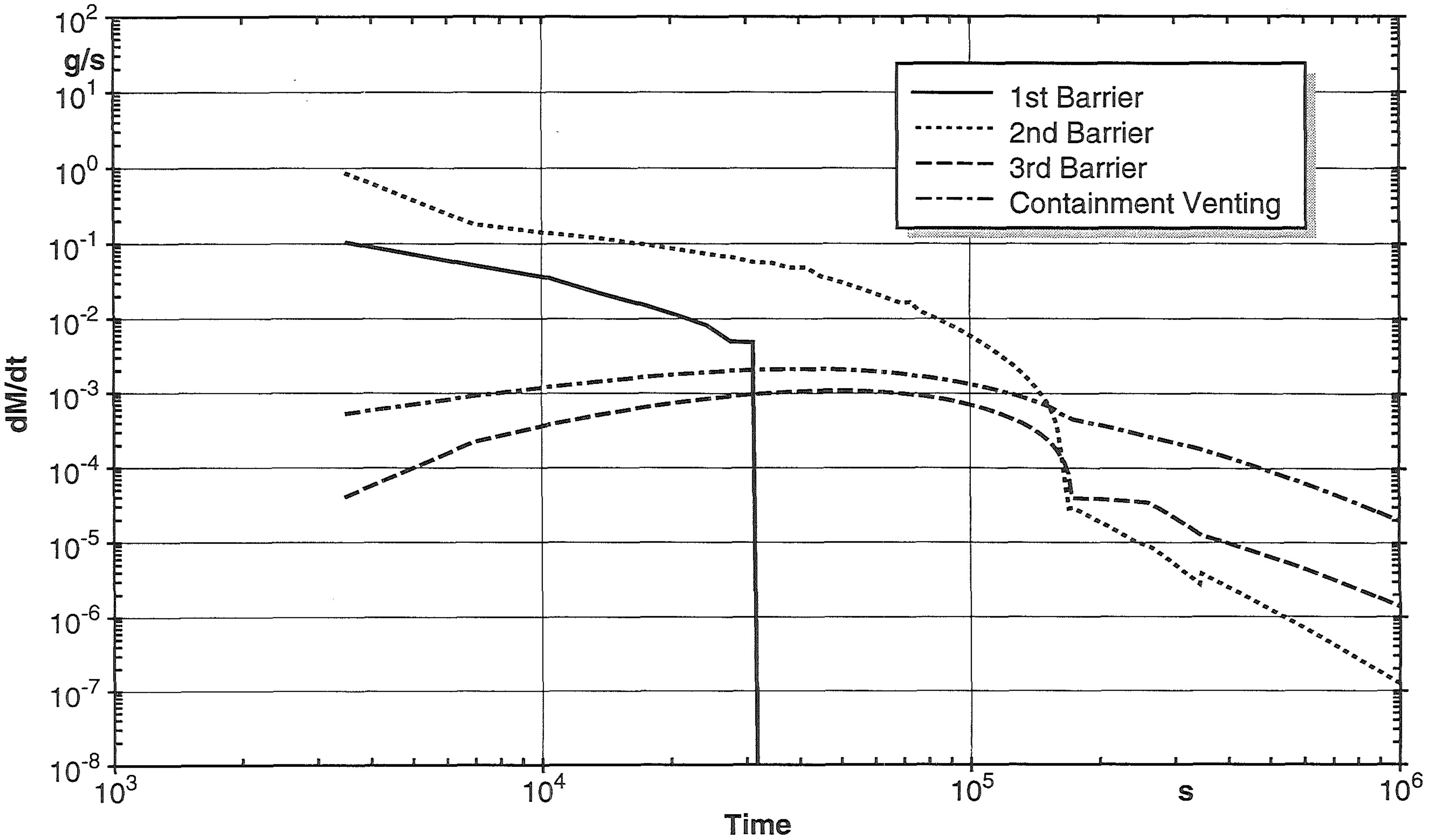

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Fig. 10 APM : Transport over Barriers

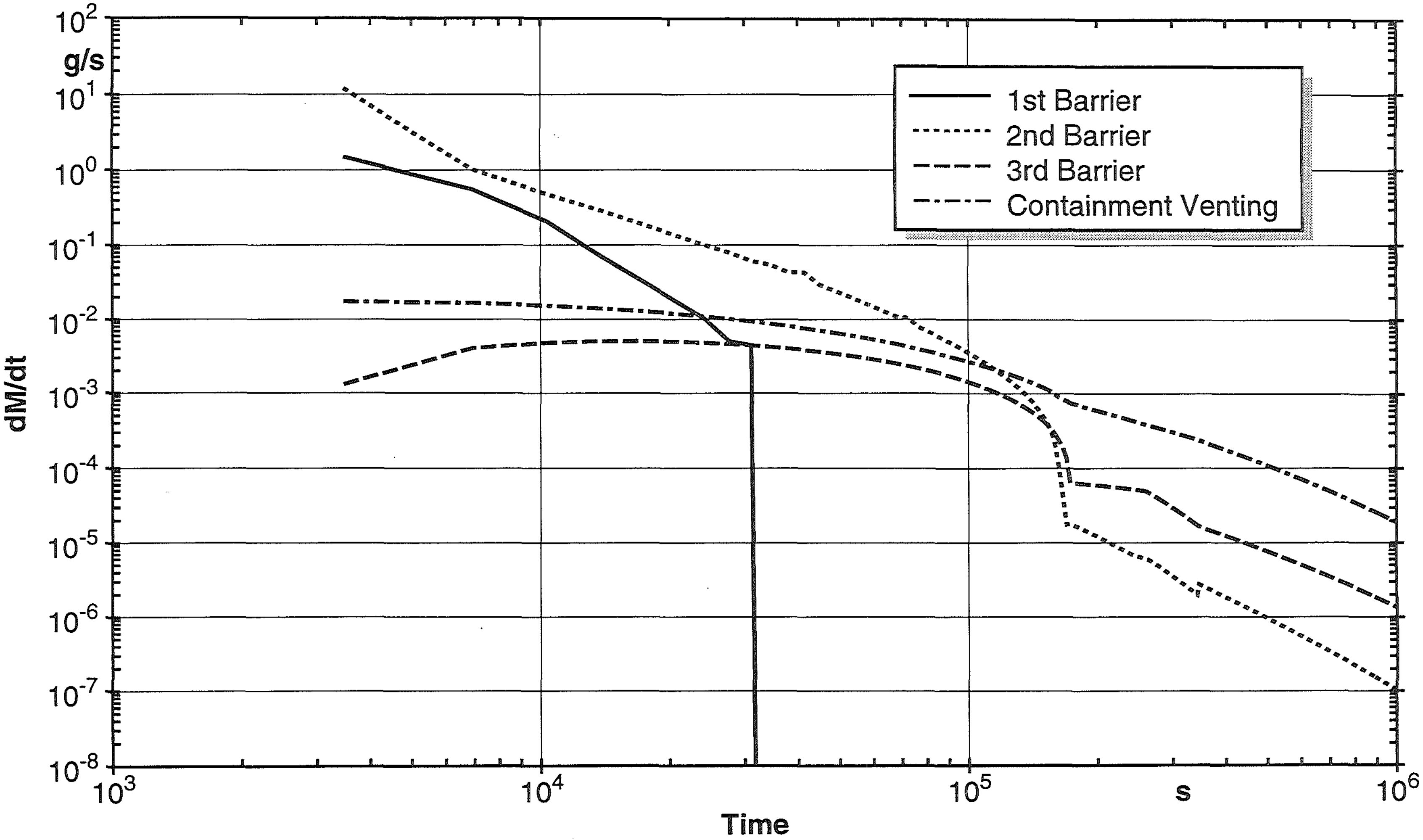

Fig. 11 APM : Transport over Barriers

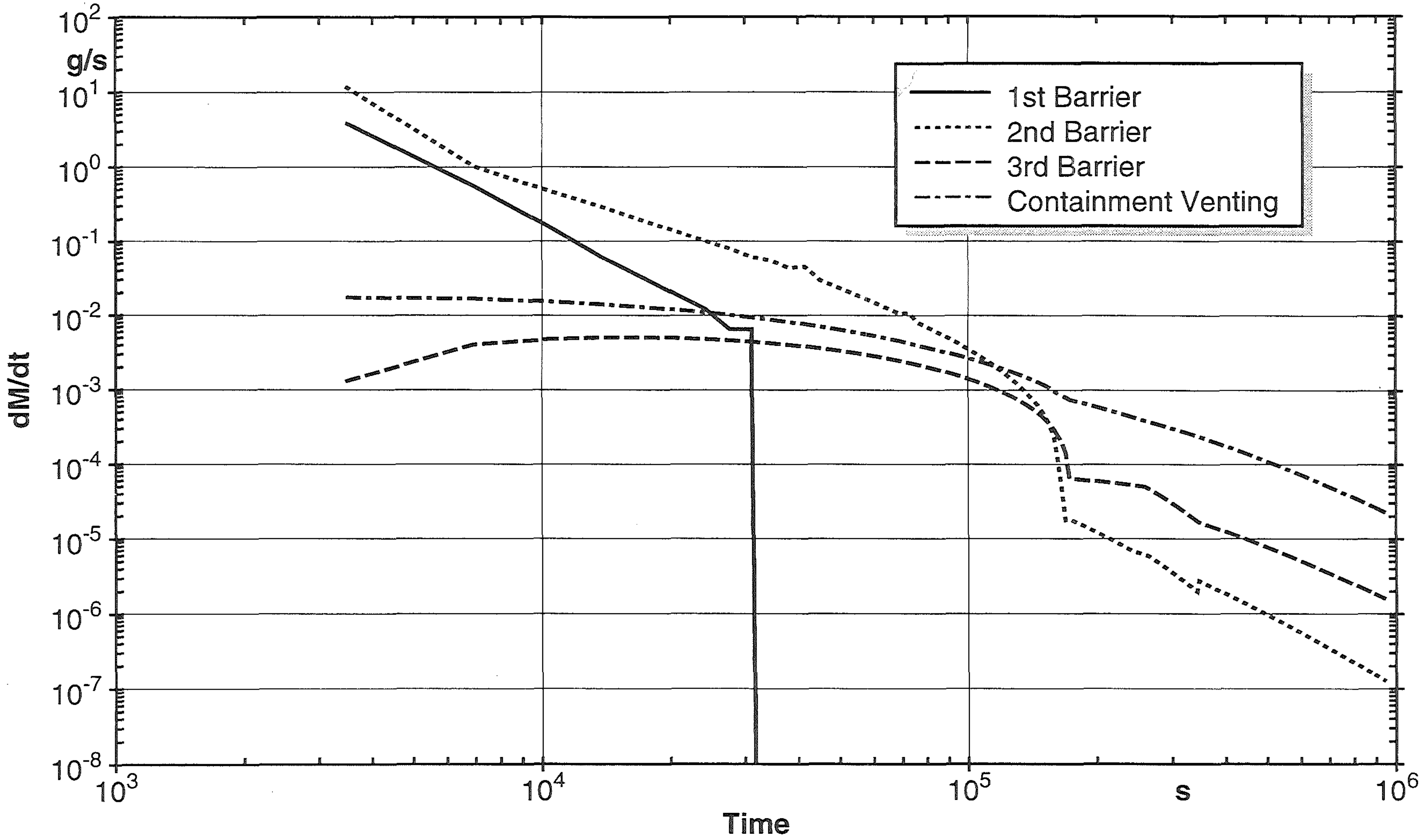

Fig. 12 APM : Transport over Barriers