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Collocation of PM2.5 Particulate Monitors and Nephelometers

Experimental Design

Harold Thistle, *Program Leader*

Andy Trent, *Project Leader*

Bob Hammer, *Hydrologist, Bitterroot National Forest*

Richard Fisher, *Air Resource Management, Washington Office*

USDA Forest Service • Technology & Development Program
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XE82P53—Remote PM2.5 Particulate Sampler

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Introduction

The Watershed, Soil, and Air (WSA) Program at the Missoula Technology and Development Center (MTDC) has two projects in Fiscal Year 1999 to field test and evaluate air-quality instrumentation. This experimental design describes the proposed details of the field testing. This design will act as guidance during this field work. The two types of instruments being evaluated are PM2.5 monitors that evaluate the amount of airborne particulate matter less than 2.5 microns in diameter and nephelometers that measure visibility in the atmosphere. This work follows a series of laboratory tests indicating that optical methods used to measure particulate concentration may be inaccurate, overestimating the actual particulate in the air. These field tests are designed to provide additional information in an ambient environmental setting.

The monitoring will take place in two phases. The first phase will be performed in the Missoula area to allow easy access to the instruments. This phase will allow shakedown of the instruments and development of maintenance procedures. Phase I will be conducted in the winter when wilderness access is difficult. Phase II will begin in the spring. Instruments will be deployed near a Class I airshed. This phase is intended to duplicate conditions under which this type of instrumentation is expected to operate in Forest Service usage.

Objective of the PM2.5 Monitor Collocation Study

The objective of the particulate monitoring instrument collocation study is to determine the accuracy of optical PM2.5 particulate monitoring instruments by comparing them to a U.S. Environmental Protection Agency (EPA) reference method in an ambient setting.

Objective of the Nephelometer Collocation Study

The objective of the nephelometer collocation study is to compare results from two instruments to decide whether the cost difference between the instruments is reflected in performance.

Statement of Problem

The Forest Service is mandated to prevent degradation of air quality in Class I airsheds. PM2.5 is now a criteria air pollutant and is considered the most important class of particulate from the standpoint of human health. Pristine visibility is one of the recognized attributes of Class I airsheds. The Forest Service has the responsibility to maintain pristine visibility in these airsheds. Interestingly, particulate in the PM2.5 and smaller size class has a substantial (often primary) effect in degrading visibility.

The interference of this small particulate with light can be quantified by measuring the back-scatter from a beam of light through air sampled in a chamber. The back-scatter (Bscat) is a measure of visibility. By applying a conversion factor, Bscat can be used to estimate the particulate mass concentration in air.

Nephelometers and many non-gravimetric particulate monitors use the same type of transducer to indicate particulate concentration and visibility. In the field tests described here, nephelometers and the optical particulate monitors are collocated not only for convenience but because the nephelometer readout can be converted to particulate mass concentration. This conversion is performed internally by optical particulate monitors. The proposed experimental design will address two separate questions.

Accuracy of PM2.5 Optical Particulate Monitors

The first question the experimental design addresses is whether optical particulate monitors can accurately indicate PM2.5 concentration. Laboratory tests indicate that optical instruments consistently overpredict particulate concentrations when ambient air is dominated by smoke particulate. Since Bscat is converted to mass concentration through a curve-fitting procedure, it is important to determine whether the overprediction can be consistently accounted for by adjusting the coefficients of the curve. This assertion is often questioned because the nature of ambient particulate is so varied. It ranges from young combustion products due to wildfires to aggregates and condensates associated with the "photo-soups" of urban fog. Even if the question is restricted to fire applications, the type of the fuel, age of the smoke, moisture content of the fuel, and humidity of the atmosphere will all play a part in the particulate's optical properties.

Optical instruments like the MIE DataRam PM2.5 sampler provide real-time monitoring. The EPA reference-method instruments use gravimetric sampling. With this method particulate is collected on a filter that has to be weighed to determine the total mass accumulated during the sampling period. This is a delicate, expensive, and time-consuming process. Forest Service managers in the field do not have the particulate concentration information for weeks. Advantages of the DataRam are its small size (about 35 by 18 by 13 cm), low weight (5 kg) and its ability to log and store data electronically. It is also relatively reasonably priced (around $10,000 with attachments) relative to other techniques. Another approach for estimating particulate mass concentration uses an oscillating cylinder that is known as a tapered element oscillating microbalance (TEOM). Accumulated particulate changes the oscillation frequency and particulate concentration is inferred from the change in frequency. This instrument is bulky and expensive.

Several DataRam PM2.5 monitors have been purchased by Forest Service personnel. It is essential to determine the accuracy and reliability of these instruments in Forest Service applications. Other manufacturers of this type of instrument include Grimm, Inc., Met-One Instruments, Inc., and Rupprecht Patashnick. We will attempt to include these instruments in these trials as they are available.

Cost-Effectiveness of Nephelometers

The project to compare nephelometers was initiated by a specific question: Can a less-expensive nephelometer meet the Forest Service's needs? The instrument currently used by the Forest Service in routine monitoring is an Op Tec NGN-2 nephelometer. The Radiance Research nephelometer is an instrument proposed as a possible alternative and it costs just 40% as much as an Op Tec nephelometer. If the lower cost instrument is as accurate and reliable, substantial savings could be realized throughout the Forest Service and a denser monitoring network might also be possible.

Since both nephelometers and optical PM2.5 monitors yield Bscat, the lower-cost Radiance nephelometer may be a legitimate choice for measuring particulate concentration. This step must be taken cautiously because the Radiance nephelometer is not marketed as a particulate monitor. The user will have to develop a conversion curve for the instrument. The DataRam might be considered as an alternative nephelometer because the manufacturer provides software to calculate visibility.

Schedule

Phase I of the study began on February 4, 1999. The Op Tec nephelometer included in the tests is available to MTDC for a limited time and will be returned in the spring of 1999. When this instrument is returned, Phase I will end and the study instruments will be pulled from the Stevensville site, brought to MTDC, and inspected, cleaned, and refurbished.

Phase II will begin on Sula Peak and continue until February 4, 2000. The time between phases will be shortened if possible. Access to the Sula Peak site may be difficult in April and May, and from November through February, due to snow and mud. The study will deal with such problems as they arise. If it is determined that access is too difficult and time consuming, the instruments may be relocated back to Stevensville or another site in October 1999.

Site

Instrument Deployment and Shelter

Six instruments have been deployed in Phase I. These include an EPA reference method gravimetric filter system manufactured by BGI, Inc., the MIE DataRam particulate monitor, the GreenTec particulate monitor made by Met-One, the Op Tec NGN-2 nephelometer and two Radiance Research nephelometers. The Op Tec instrument planned for Phase I is on loan and will be returned to its owners during the spring of 1999, marking the end of Phase I. Instruments will be pulled and redeployed during Phase II. MTDC will attempt to find an Op Tec nephelometer to replace the one being pulled at the end of Phase I. The Phase I site also includes a TEOM (configured to monitor PM10) because one is permanently deployed at the Stevensville, MT, site. The Phase I site is also a second-order National Oceanic and Atmospheric Administration (NOAA) weather station and provides daily readings of max/min temperature, humidity, and precipitation. These readings will be useful in data interpretation.

Phase II will begin during the spring of 1999. At this time, a DataRam PM2.5 monitor, a GreenTec (Met-One) particulate monitor, a Radiance nephelometer, and a BGI, Inc. EPA reference gravimetric filter sampler will be deployed at the Sula Peak Interagency Monitoring of Protected Visual Environments (IMPROVE) station. This station currently operates IMPROVE Module I. More IMPROVE modules may be added during 1999. MTDC will provide temperature, humidity, wind speed, and wind direction instrumentation at this site.

The instruments will require a shelter. A shelter has been modified to meet the specifications of the IMPROVE network and is being used at Stevensville. This shelter will be moved and used as an IMPROVE shelter at the conclusion of this study.

Site Description

The Phase I site is in Stevensville on the north edge of the town, at 3320 feet above sea level (Appendix A). The site is in the central Bitterroot Valley. The valley is about 15 miles wide at this point and remarkably flat. This valley bottom is a high-steppe climate, and receives around 12 inches of water-equivalent precipitation a year. The area is subject to frequent inversions and occasional serious air-pollution episodes caused by residential wood burning in the winter, and by wildfire—primarily in late summer. The site is located at the Stevensville Ranger District Office of the Bitterroot National Forest.

The Phase II site is at Sula Peak (Appendix A) and is currently used as a module 1 IMPROVE site. It is a low peak in the upper Bitterroot drainage near Sula, MT. This site's elevation is 6190 feet and provides access to relatively pristine air from Class I airsheds to the west and the surrounding National Forests.

Sampling

Frequency

The optical electronic instruments to be deployed are capable of sampling at frequencies higher than necessary for this study. The reference method filter will be changed twice weekly and is timed to sample for 24 hours between collections. Thus, the critical data from the electronic instruments will be a daily average, synchronized with the filter collection. Correlation with the weather data and inter-instrument comparisons are also of interest. During Phase I, the weather data will generally consist of daily measurements. The electronic data will be averaged to daily values when comparing them to the meteorological data. During Phase II, higher frequency weather data will be collected. A time-series comparison with the electronic particulate data is of interest. Given these considerations, it is probably not necessary to collect particulate concentration data more frequently than once per minute. Lower frequency data collection will suffice for much of this study.

Data Collection

Data collection will be performed twice a week. At this time, filters will be collected and replaced. All instrument data will be downloaded to minimize the data at risk in the field. During Phase I, data collection will be performed by MTDC staff (Appendix B, Safety Plan). Data will be collected and electronic data will be backed up. Weather data are collected daily at the Stevensville station independent of this study. In Phase II, MTDC personnel will coordinate with Forest Service personnel performing the data collection on the Sula Peak IMPROVE station. IMPROVE data are collected once per week. An additional data collection trip will be performed weekly to collect a second filter. Same-day backups will be made of all of the electronic data.

Quality Assurance/ Quality Control (QA/QC)

Data sets will be scanned for spikes, zeros, and out-of-range values. Comparisons will be performed to make sure data are tracking reasonably well among instruments. Data will be processed and analyzed on an ongoing basis so that instrument and sampling problems can be identified and corrected. Certain data problems such as noise or inducted harmonics can be subtle. MTDC will have the instrument deployments (Phases I and II) reviewed by an electrical engineer to try to spot such problems before they show up in the data.

Project Staffing and Responsibilities

The project is designed so that it can be staffed entirely by MTDC if necessary. It is hoped that Phase II can be coordinated with ongoing sampling. This will reduce the time and cost to the project(s). Andy Trent (MTDC) will be the Project and Technical Leader of this work and Harold Thistle (MTDC) will give technical and administrative support. Mike Huey (MTDC) will provide fabrication support with shelter and mounting and is experienced in data collection. He will have the primary MTDC data-collection role in Phase II, supported by Trent and Thistle. MTDC will also use in-house technician support to facilitate this project. Data backup and analysis will be organized by Andy Trent. A backup process will be developed to use in-house computer technical support. A QA/QC process will be developed by Trent and Thistle and designed so most of the QA/QC can be performed immediately after backup.

Reporting

Reporting on this project will take place in calendar year 2000. An MTDC report will be prepared by Andy Trent. A proceedings paper will also be prepared. The work will be evaluated for the possibility of a peer-reviewed journal article. These technical papers may extend reporting on this work into calendar year 2001.

About the Authors

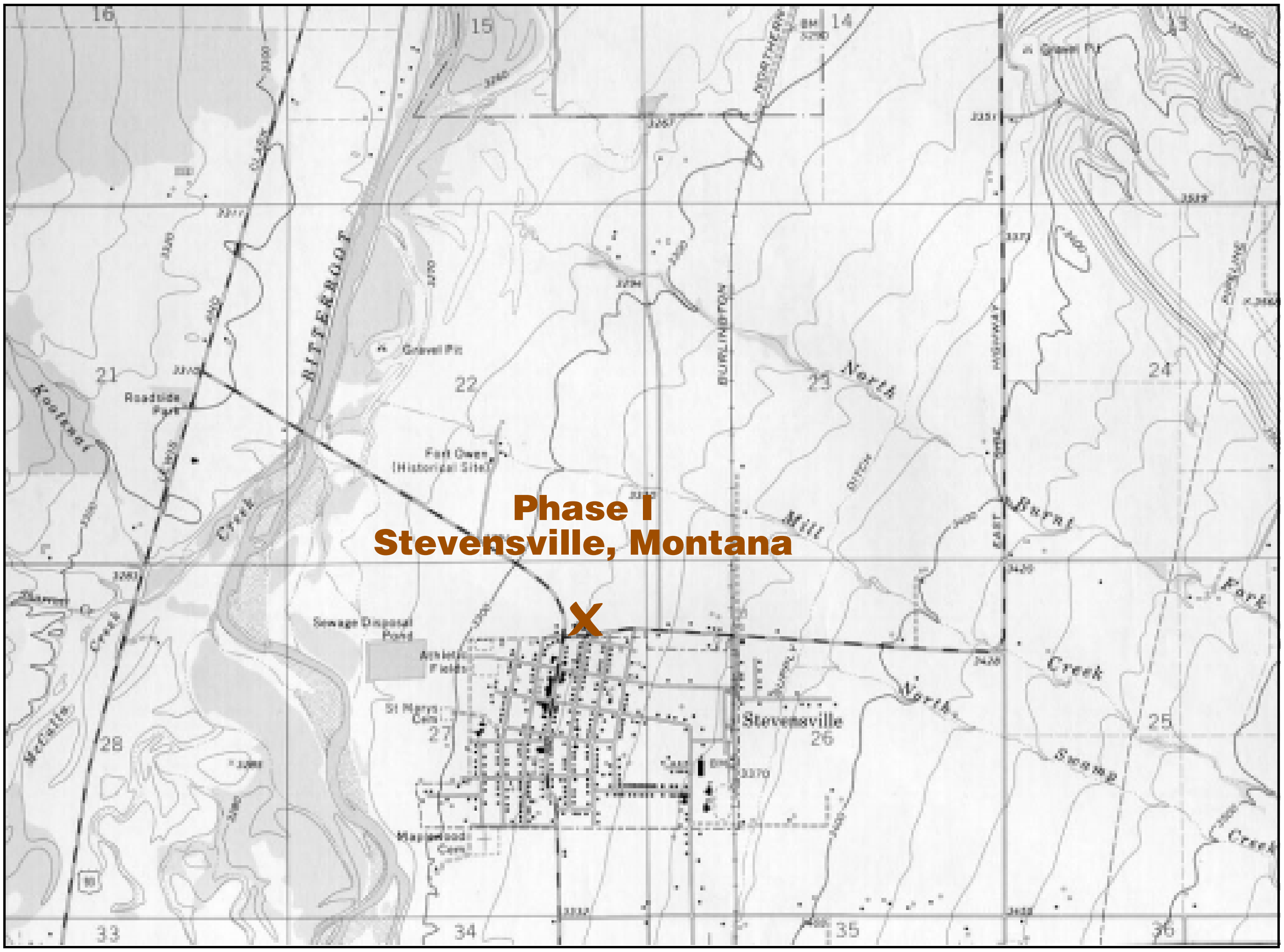
Harold Thistle received a Ph.D. in plant science specializing in forest meteorology from the University of Connecticut in 1988. He is an American Meteorological Society Certified Consulting Meteorologist, and has worked as a consultant in private industry before joining MTDC in 1992. As the Center's Program Leader for Forest Health Protection, he develops modeling techniques that accurately describe transport of pesticides in the atmospheric surface layer and he evaluates meteorological instrument systems for environmental monitoring.

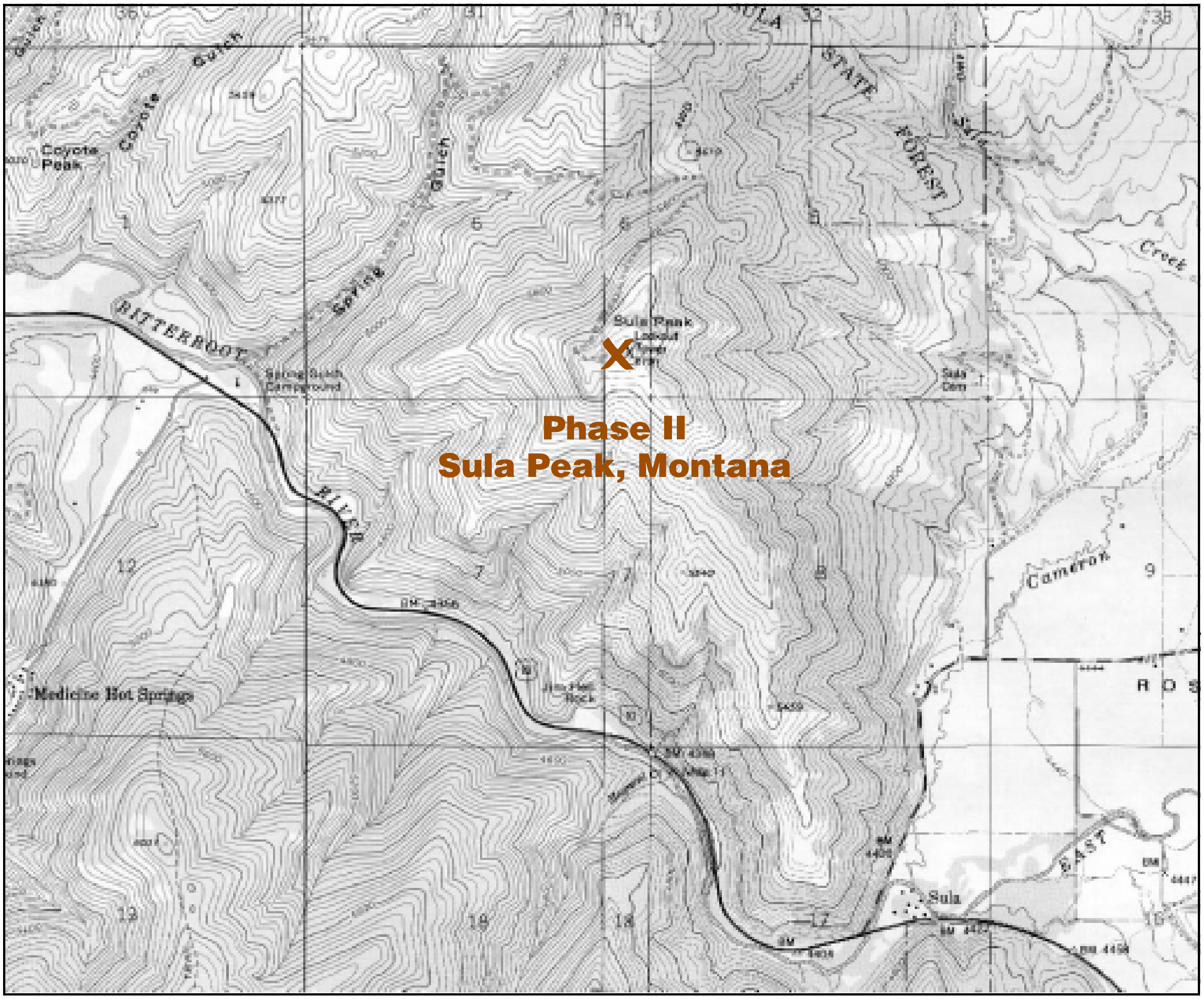
Andy Trent is a Project Engineer at MTDC. He received his bachelor's of science degree in mechanical engineering from Montana State University in 1989. He came to MTDC in 1996, and works on projects for the Nursery and Reforestation, Forest Health Protection, and Watershed, Soil, and Air programs.

Bob Hammer is a hydrologist for the Bitterroot National Forest in Hamilton, Montana. He works with air quality and weather. He has a bachelor's degree in forestry from the University of Montana, a bachelor's degree in mathematics from Oregon State University, and a master's degree in meteorology from the University of Michigan.

Richard Fisher has bachelor's degrees in life science from the U.S. Air Force Academy, and in meteorology from North Carolina State University. He holds master's degrees in earth science from Colorado State University, and in international and strategic studies from the Naval War College. He is an American Meteorological Society Certified Consulting Meteorologist, and is Reserve Assistant to the Director of Weather for the U.S. Air Force in the Pentagon.

Appendix A—Site Maps




Phase II
Sula Peak, Montana
X
Sula Peak
Coyote Peak
Coyote
Gulch
Spring
BITTERROOT
RIVER
Spring Gulch Campground
SULA
STATE
FOREST
Creek
Cameron
Medicine Hot Springs
Sula
EAST

Appendix B—Safety Plan

All MTDC and local safety precautions will be followed during this program. Personnel are local and are aware of medical facilities. The closest hospital to the site is the Marcus Daly Memorial Hospital in Hamilton, MT. The telephone number is (406) 363-2211.

A cellular phone will be carried during Phase II. The primary safety hazard in this work is travel to and from the site.

All personnel will have the appropriate credentials to operate the motor vehicles involved. An electrical engineer will evaluate the instrument installations for electrical hazards.

Library Card

Thistle, Harold; Trent, Andy; Hammer, Robert; Fisher, Richard. 1999. Experimental design: collocation of PM2.5 particulate monitors and nephelometers. Tech. Rep. 9925-2825-MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 9 electronic p.

Describes proposed field tests to determine the accuracy of PM2.5 monitors that evaluate the amount of airborne particulate matter less than 2.5 microns in diameter and nephelometers that measure visibility in the atmosphere. The PM2.5 monitors and nephelometers can measure particulate concentrations in real-time, but the laboratory tests have shown that they may overestimate the concentration. Gravimetric particulate samplers are more accurate, but they require collecting particulate on a filter and weighing the filter in a laboratory. Managers do not get the data for weeks. This test will compare the results from a gravimetric sampler to those of PM2.5 monitors and nephelometers over a period of months at two field sites in Montana.

Keywords: air pollutants, air quality, nephelometry, smoke management

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USDA Forest Service, MTDC
Building 1, Fort Missoula
Missoula, MT 59804-7294
Phone: (406) 329-3900
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E-mail: pubs/wo_mtdc@fs.fed.us

For additional technical information, contact Harold Thistle or Andy Trent at the address above.

Harold Thistle
Phone: (406) 329-3981
Fax: (406) 329-3719
IBM: hthistle/wo,mtdc
E-mail: hthistle/wo_mtdc@fs.fed.us

Andy Trent
Phone: (406) 329-3912
Fax: (406) 329-3719
IBM: atrent/wo,mtdc
E-mail: atrent/wo_mtdc@fs.fed.us

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