Scientific Use of Fiber-Optic Submarine Telecommunications Cable Systems

Rhett Butler  
Director, IRIS Ocean Cable  
1200 New York Avenue NW, Suite 800  
Washington, DC 20005  
rhett@iris.edu

Introduction. The first generation of fiber optic submarine cables began a revolution for telecommunication. The bandwidth available in these systems truly created the information superhighway across the oceans between North America, Europe, Japan, and other centers of digital culture. The development and installation cost of these systems exceeded $2,000,000,000. These electro-optical systems, though state-of-the-art in their time, have now been surpassed by purely optical systems with vastly greater capabilities. Because the second-generation systems are purely optical, using in-line lasers to amplify the signals rather than electro-optical regenerators, they may be upgraded “in place”—by changing only the terminal equipment the bandwidth may be increased by 1-2 orders of magnitude. This versatility coupled with the current underutilization of existing fiber capacity (estimated at less than a 10%), has led to the decision of telecommunications companies to retire their first generation fiber optic systems more than decade earlier than originally planned. This presents an extraordinary opportunity for science.

Cabled Seafloor Observatories are essential to the Ocean Sciences (NRC, 2000), and the intellectual merit and broader impacts of these observatories have been discussed in a succession of NSF workshops and NRC reports. These fiber optic telecommunications cables being retired by the telecommunication industry are now being offered for scientific reuse by AT&T, and are in discussions with the overseas owners. These Cable Systems include three Pacific systems—Hawaii-4, Trans-Pacific Cable-3 (TPC-3), Guam-Philippine-Taiwan (GPT)—and four Atlantic Systems—Trans-Atlantic-8 (TAT-8), TAT-9, TAT-10, and TAT-11 (Figure 1). The transfer of these systems to science is currently in negotiations (July, 2003). A facility for ownership transfer is IRIS Ocean Cable, Inc. (IOC), a not-for-profit corporation formed by The IRIS Consortium in consultation with the National Science Foundation to acquire ownership of retired telephone cables for science. IOC currently owns two retired coaxial telephone cables: TPC-1 (Guam-Japan) with the University of Tokyo (Kasahara et al., 1998) and Hawaii-2, which serves the NSF-funded Hawaii-2 Observatory (H2O) (Butler et al., 2000).

Figure 1. The TPC-1 and Hawaii-2 coaxial submarine telephone cables were transferred for scientific use in the 1990’s. Seven first generation fiber optic Cable Systems are now being retired, and are being considered for scientific use.
Four of these fiber systems—TAT-8, TAT-10, TAT-11, and GPT—have already retired, and the other three aforementioned systems will be retired by the end of the year. There are three additional first generation systems in the Pacific (TPC-4, Hawaii-5, and PacRimEast, see Figure 2) that will likely be retired in the coming years. Because the telecommunications companies move quickly (typically with a six-month time frame) after a system’s retirement to dispose of the equipment and spares (and in Europe and Japan to remove cable from the coast) it is essential to act now if the scientific community wishes to retain any options for using these cables for science in the future. As the scientific community and NSF develops consensus for use of these systems for science, focus must be directed to establish a framework for the basic infrastructure and management necessary toward acquiring these systems for scientific use.

The Director of IRIS Ocean Cable—in consultation with the National Science Foundation and with approval of the IRIS Executive Committee and Board of IRIS Ocean Cable, Inc.—has been actively working with AT&T and their Cable System partners since July 2002 to make arrangements for the scientific re-use of these first generation fiber systems. There are no fundamental impediments for the Pacific Cable Systems—transfer of systems and spares has been agreed to, in principle, by the respective System Owners (a draft system transfer agreement has been submitted for consideration, a transfer agreement for GPT spares has already been signed), license space in cable stations (a draft license agreement has been submitted for consideration) and storage space for spares is being negotiated. The donation of equipment schematics encompassing both Pacific and Atlantic Systems has been accomplished. For the Atlantic Systems, discussions are underway with AT&T and their 50 European partners.

Scientific Opportunities. The scientific importance of cabled seafloor observatories has been fully documented in a series of National Research Council reports, NSF sponsored workshops, and National Ocean Partnership Program reports. The Executive Summary of *Illuminating the Hidden Planet, the Future of Seafloor Observatory Science* (NRC, 2000) begins

> Earth's oceans are essential to society as a source of food and minerals, a place of recreation, an economic means of transporting goods, and a keystone of our national security. Despite our reliance on the ocean and its resources, it remains a frontier for scientific exploration and discovery. Scientists have been using ships to explore the ocean with great success over the past 50 years and this mode of expeditionary science has led to remarkable increases in oceanographic knowledge. A ship-based expeditionary approach, however, is poorly suited for investigating changes in the ocean environment over extended intervals of time. To advance oceanographic science further, long time-series measurements of critical ocean parameters, such as those collected using seafloor observatories, are needed (NRC, 1998).

Additional information may be found at www.iris.iris.edu/cable/info.htm
Figure 3. Maps of TransAtlantic Cables highlighting TAT-8, TAT-9, TAT-10, and TAT-11 with respect to other cable systems. Note locations (green squares) of last AT&T repeaters for TAT-8, TAT-9, and TAT-11. TAT-10 has all AT&T repeaters (complete TAT-10 map shown in Figure 4).

Additional information may be found at www.iris.iris.edu/cable/info.htm
For the purpose of this report the term “seafloor observatories” is used to describe an unmanned system of instruments, sensors, and command modules connected either acoustically or via a seafloor junction box to a surface buoy or a fiber optic cable to land. These observatories will have power and communication capabilities and will provide support for spatially distributed sensing systems and mobile platforms. Instruments and sensors will have the potential to make measurements from above the air-sea interface to below the seafloor and will provide support for in situ manipulative experiments.

NRC (2000) further discusses the Cabled Systems envisioned, and highlights the re-use of retired commercial cable systems:

Cabled seafloor observatories will use undersea telecommunications cables to supply power, communications, and command and control capabilities to scientific monitoring equipment at nodes along the cabled system. Each node can support a range of devices that might include items such as an Autonomous Underwater Vehicle (AUV) docking station. Cabled systems will be the preferred approach when power and data telemetry requirements of an observatory node are high. Early generation commercial optical undersea cable systems that are soon to be retired will have the communications capacity to satisfy most anticipated observatory research needs, but will possibly have insufficient power capability. [note: see discussion of power in Table 2.] If these cables are suitably located for observatory research studies, their use could be explored to reduce the need for expensive new cable systems.

As it is likely that cabled observatories would be installed at a site for a decade or more, substantial engineering development will be required in the design and packaging of the power conditioning, network management, and science experiment equipment. In order to meet the requirements for high system-operational time (versus downtime), low repair costs, and overall equipment lifetime, significant trade-offs will have to be considered between the use of commercially available and custom-built equipment.

Two specific recommendations in NRC (2000) are particularly relevant:

2. A comprehensive seafloor observatory program should include both cabled and moored-buoy systems, ... and (5) A seafloor observatory program should include funding for three essential elements: basic observatory infrastructure, development of new sensor and AUV technology, and scientific research using seafloor observatory data.

The NOPP (2001-2002) report An Integrated Ocean Observing System: A Strategy for Implementing the First Steps of a U.S. Plan points to cables as one of the key platforms, including satellites, drifting and fixed buoys, autonomous vehicles and state-of-the-art ships, for collecting a variety of oceanographic data. Clark (2001) notes that, “The primary infrastructure of the OOI [Ocean Observatory Initiative] is a set of seafloor junction boxes connected to a series of cables running along the seafloor to individual instruments or instrument clusters.”

The Scientific Cabled Observatories for Time Series (SCOTS) Committee was initiated by the National Science Foundation in April 2002 through the Dynamics of Earth and Ocean Systems (DEOS) Steering Committee to provide advice regarding the planning and implementation of the NSF Ocean Observation Initiative (OOI). The SCOTS Steering Committee’s primary focus was to elucidate the scientific questions that require, or would most effectively be addressed by, regional networks of multidisciplinary cabled observatories in three generic domains—the open ocean, geologic plates, and coastal. Among the general observations of the SCOTS report (Glenn and Dickey, 2003), two points are directly relate to the use of cables:

1. Cabled Observatory Science: Scientists attending the workshop identified important scientific questions within six science themes that could be addressed because of several attributes of cabled observatories. In particular, the capability of cabled observatories to: (1) supply power sufficient for energy demanding sensors and systems, (2) sample at high data rates for long periods, (3) collect a large number of virtually continuous and diverse measurements over different spatial scales for...
unprecedented interdisciplinary coherence analyses, and (4) communicate the full datasets to shore in real-time time enables new classes of scientific questions to be addressed.

4. Both New and Used Cables: It was determined that cabled observatories could be developed through initiation of completely new cabled systems and by taking advantage of abandoned cables that would be donated by the commercial sector. Both models have already proven successful and could be pursued for specific scientific problems and applications.

Among the recommendations of the SCOTS report:

2. Retired Telecommunications Cables: There was widespread support for relocating retired telecommunications cables to remote areas to complete the deep Earth imaging array. While this may be one of the primary considerations for determining the new locations, once in place, the cable could support a much wider variety of sensors and systems to facilitate ocean studies also desired by the fluids and life and the ecosystem working groups. It is recommended that current and future funding mechanisms be used to ensure that retired cables deemed to be scientifically useful are adopted for community use in a timely manner.

The National Science Foundation has already given approval to the University of Hawaii to re-focus the MRI funded Aloha Observatory Project for connecting the Hawaii Ocean Time Series (HOTS) site to HAW-4 fiber cable instead of the previously proposed ANZCAN-D coaxial cable. New Zealand has expressed interest to NSF regarding possible re-use of a section of TPC-3 re-deployed between the South Island of New Zealand and the Pacific-Antarctic Ridge. IRIS is working closely with the DEOS Cable Re-Use Committee in order to advise the scientific community regarding these cable opportunities, and to seek guidance for the decisions that will need to be made regarding which Cable Systems and spares the scientific community should acquire.

Cable System Characteristics. All of the first generation fiber systems are electro-optical systems that regenerate the optical signals electronically in the repeaters. The systems are powered from the shore Cable Station, and operate in a constant current mode at 1.6 Amps. The Power Feed Equipment (PFE) is standardized for these systems, and typically operates at about 5 kiloVolts (kV). Systems may be powered from one or both ends, depending upon the length of cable. Each repeater draws power and there are losses in transmission due to resistance in the copper. Table 1 shows the power characteristics of the systems (derived with Mr. David Gunderson).

<table>
<thead>
<tr>
<th>Cable</th>
<th>Cable Station &amp; Section with AT&amp;T Repeaters</th>
<th>Average Section Length, km</th>
<th>Average Repeater Spacing, km</th>
<th>Number of Repeaters</th>
<th>Average Repeater Voltage Drop, Volts</th>
<th>Copper Voltage Drop, Ohms per km</th>
<th>Copper Voltage Drop per Span</th>
<th>Copper Voltage Drop per 1000 km</th>
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<tr>
<td>HAW-4</td>
<td>Makaha, HI - Point Arena, CA</td>
<td>4263</td>
<td>71.0</td>
<td>60</td>
<td>1.6</td>
<td>22.3</td>
<td>0.7</td>
<td>78.0</td>
</tr>
<tr>
<td>TPC-3</td>
<td>Makaha, HI</td>
<td>5265</td>
<td>69.9</td>
<td>76</td>
<td>1.6</td>
<td>22.3</td>
<td>0.7</td>
<td>77.1</td>
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<td>TPC-3</td>
<td>Tanguisson, Guam</td>
<td>1383</td>
<td>49.4</td>
<td>28</td>
<td>1.6</td>
<td>22.3</td>
<td>0.7</td>
<td>61.0</td>
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<tr>
<td>GPT</td>
<td>Tanguisson, Guam</td>
<td>2293</td>
<td>69.8</td>
<td>33</td>
<td>1.6</td>
<td>22.3</td>
<td>0.7</td>
<td>77.1</td>
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<tr>
<td>TAT-8</td>
<td>Tuckerton, NJ</td>
<td>5880</td>
<td>67.0</td>
<td>88</td>
<td>1.6</td>
<td>22.3</td>
<td>0.7</td>
<td>74.8</td>
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<tr>
<td>TAT-9</td>
<td>Manahawkin, NJ</td>
<td>4390</td>
<td>99.2</td>
<td>43</td>
<td>1.6</td>
<td>43</td>
<td>0.7</td>
<td>120.8</td>
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<td>TAT-10</td>
<td>Green Hill, RI</td>
<td>7197</td>
<td>131.1</td>
<td>55</td>
<td>1.6</td>
<td>43</td>
<td>0.7</td>
<td>145.8</td>
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<tr>
<td>TAT-11</td>
<td>Manahawkin, NJ</td>
<td>3244</td>
<td>138.8</td>
<td>23</td>
<td>1.6</td>
<td>43</td>
<td>0.7</td>
<td>151.8</td>
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</tbody>
</table>

The power available for a seafloor observatory depends upon the length of cable being powered, as the voltage losses average about 1.5 V/km for all systems. Margin must be included for voltage variations due to the Earth’s magnetic field, which are typically 0.1 V/km (at high latitudes, 2-3 times greater). The PFE may be operated safely with an additional load of 2.5 kV—up to about 7.5 kVolt total—permitting margin for additional power if required. Therefore, several kilowatts (kW) of power are potentially available for seafloor observatories connected to sections of these cable systems, with substantial margin, as noted in Table 2 for various cable lengths.
The Terminal Transmission Equipment (TTE) in the Cable Stations contains the optical transmit/receive equipment that provides the physical layer of the transmission. The SL260 and SL580 system TTE are of AT&T and Alcatel design, respectively. The TTE works in conjunction with the Home Supervisory Unit (HSU) for fault location, for switching spare lasers within repeaters and switching fiber spans between repeaters. Repeaters occur at 50-140 km intervals along the systems, and electronically regenerate the optical signal. Because the repeaters already contain an electronic interface with the systems, the repeater itself presents the only possible means to connect an ocean observatory. The transmission protocol carries Plesiosynchronous Digital Hierarchy (PDH, plesio means near). The transmission speed is 295.6 Mb/s per fiber pair for SL280 systems and 591.2 Mb/s per fiber pair for SL560 systems, the transmission protocol being a simple multiple of the SL280. Table 3 shows the bandwidth for the systems.

The systems were conservatively designed for an operational lifetime of 25 years. Given the extremely rigorous standards imposed by AT&T, the equipment will probably be operational for additional decades. Earlier generation retired SD coaxial systems (Hawaii-2 and TPC-1) donated to IRIS Ocean Cable, Inc., after 25 years of telephone service have operated without problems for an additional decade. The nominal retirement date for these fiber systems installed 1988-1993 is 2013-2018. These systems are being retired early only because newer generation fiber systems using purely optical repeaters have up to 1,000 times the bandwidth, and therefore the older systems are no longer commercially viable. The SL equipment is very robust, with internal redundant back-up systems. A review of component failures with AT&T indicates only about a half-dozen, random individual laser failures over the hundreds of repeaters over the lifetime of all 7 of these systems, and only two instances (TAT-8 and GPT) of span changes requiring use of the spare fiber link between two repeaters.

Because the cable equipment maintenance and storage facilities were sold by AT&T several years ago to Tyco Telecommunications, the original system drawings and schematics of the cable repeaters and station plant are Tyco property. The Director of IRIS Ocean Cable met with Tyco on April 15 requesting the donation of these schematics to IOC on behalf of the scientific community. Tyco has graciously agreed to provide all of the information that they have for the aforementioned systems. Working with Mr. Mark Tremblay, the schematics necessary for scientific re-use have already been transferred to IOC.

Ownership. A consortium of owners owns each of the cable systems, with AT&T being a large stakeholder. Some of the TAT cables have more than 40 European owners. The owners coordinate through a General Committee. Approval in principle for the scientific re-use of Hawaii-4/TPC-3 by AT&T and KDDI Japan has been given, and
Transfer/License Agreements have been drafted and submitted to IRIS Ocean Cable, Inc., by AT&T on behalf of the GPT Owners. When the GPT Agreements are concluded, they will serve as a template for the transfer of the other systems. For the Trans-Atlantic Systems, IOC is discussing ownership for the scientific community only of those Cables Systems (and sub-sections thereof) connected to AT&T Cable Stations. This decision is based upon
1) Cable Station space availability, 2) equipment standards, 3) fishing/trawling problems at the European coast, and 4) avoidance of foreign liability and environmental clean-up obligations. Discussions with the European Owners for transfer of the TAT systems have not yet led to an agreement-in-principle, and there is expressed reluctance on their part due to concerns about future liability.

Cable Stations. There is available space in each of the AT&T Cable Stations. AT&T has no presence outside of the US for these systems, and any arrangements with a foreign cable station must be with the respective overseas telecommunications company that operates the station. AT&T has offered to provide license space for scientific use, in much the same fashion as done for TPC-1 at the Guam Tanguisson Station and for Hawaii-2 at the Hawaii Makaha Station. This space is valuable. The current commercial rates for the fiber Cable Systems are of the order of $100-300K/yr. Current yearly cable station license costs for the scientific use of TPC-1 and Hawaii-2 are about $15K/yr/each, which are more than an order of magnitude lower than standard commercial rates. Space needs (and hence License costs) for the scientific equipment should in principle be less than commercial needs, as much of the multiplexing equipment is not required for scientific use. Scientific use of any of these Systems will likely take several years. It may be possible to defer Cable Station costs, either by removal of equipment from the Stations, and by other arrangements with AT&T; these are being actively explored. However, it will be important to preserve the option for use of the Cable Station.

The Manahawkin Cable station in New Jersey, which services only TAT-9 and TAT-11, is a unique case in that it may be closed upon retirement. The station itself is located in a Fish and Wildlife Preserve, and the disposition of the land and station is still under discussion at AT&T. Upon introduction by IOC to AT&T during a visit to Manahawkin in May, Rutgers University, which operates the nearby LEO-15 scientific cable, has entered discussions with AT&T about the possibility for donating this facility to them. Unless ownership issues regarding the Manahawkin Cable Station can be successfully resolved within the context of the retirement of these Cable Systems, the scientific use of the TAT-9 and TAT-11 systems remains unlikely.

Equipment Standardization. There is a high degree of standardization in the AT&T equipment, both for the terminal and repeaters, and within the two types of the first generation SL280 and SL560 equipment. There is universal joining equipment for splices. However, the actual hardware installed by AT&T and their partners is not the same. The terminal equipment oversees is different from AT&T. More importantly, sections of repeaters change depending upon who was responsibility for a section of the system. For instance, the TPC-3 system uses Japanese KDDI repeaters west of the Branch, and AT&T repeaters eastward. Similarly, TAT-8 has AT&T repeaters from New Jersey to the Branch near UK and France, after which British and French repeaters respectively are used. TAT-9 and TAT-11 have AT&T repeaters only part way across the ocean. Significantly, AT&T repeaters cannot simply be controlled and monitored by an overseas cable station, and vice versa (although the repeater will blindly retransmit the signal if it is the correct format). HAW-4, GPT, and TAT-10 have only AT&T repeaters. In order to work within the AT&T standard, this discussion focuses only on the Cable Systems and sections of Cable Systems, which have AT&T repeaters. In general, these include all cable sections connected to AT&T Cable Stations.

Cable Burial and Fishing. AT&T buries its cable to protect against fishing and trawling activities. This is not a problem in the Pacific, where
the water gets deep very quickly, but has been a significant problem in the Atlantic. Nearly all of the cable fault problems in the Atlantic occur on the European side, where sufficient measures were not taken by the European partners to bury the cable in the shallow, near continental margin. This has created a continual problem in Europe from fishing trawlers and cable chafing by currents at the seafloor. For AT&T the problem rate on the US side of the Atlantic has been only 1 fault per 5 years per 6 cable systems (1 fault per 30 cable-system-years). Even though the fault history is very good for AT&T systems, careful review of the actual history indicates that the only system with such problem is TAT-8 on the New Jersey shelf beyond the first repeater.

Liability and Environmental Clean-up Obligations. The IRIS Consortium formed IRIS Ocean Cable, Inc. (IOC) as a 501(c)(3) not-for-profit corporation for cable ownership and license agreements for the acquisition of TPC-1 and Hawaii-2 for science, and can provide a vehicle for the transfer of the fiber optic Cable Systems. The License Agreements dictate operational requirements for having equipment in the Cable Station, which includes its removal upon termination of the License Agreement. There are liability issues in owning something on the seafloor (the cable itself). If a fishing trawler snags the cable and loses his net, traditionally AT&T paid them to replace the net. However, IOC has no assets but the Cables. Marine insurance will be obtained, but as noted the stronger step of avoiding Cable Systems with a history of fishing related problems is a more conservative course.

The US has no law that requires AT&T to remove the cable from the shallow coastal region upon retirement. Recently New Jersey passed a law requiring removal of new cable systems from their coast, which does not affect the older TAT systems. In accepting TPC-1 and Hawaii-2, IOC will not have to remove the cables once the systems are retired from scientific use. However, IOC will have to remove equipment from its license space at the cable stations upon project completion. Similarly, a US scientific entity such as IOC would not have to remove a fiber optic cable from the seafloor of the US coast after scientific retirement.

This is not the case for the European systems. When the four TAT Systems (8, 9, 10, and 11) are retired, the Owners will hire a cable ship to remove the cables from the European coast. If these sections of cables are donated to science, then the scientific entity would in principle have to remove the cable after retirement from scientific use. This is a substantial obligation (perhaps prohibitive with typical scientific funding). Since the re-use of commercial cable systems or any new scientific cables on the coast of Europe faces similar restrictions, the European community will need to carefully evaluate the future implied costs for cable systems.

Similar asymmetry of law exists for cables landing in Japan versus the US. For TPC-1, IRIS entered into a memorandum with the University of Tokyo obligating the Japanese side to be responsible for Japanese coastal clean up. A similar arrangement may be possible with TPC-3, if the Japanese scientific community decides to re-use the western portion of the system.

As NSF looks to laying its own coastal and regional cable systems (e.g., NEPTUNE) the fishing and liability issues are part of the opportunity that must be considered.

Spares. AT&T is making available all of its spare cable and equipment for these systems. There are 23 SL560 system repeaters and 15 SL280 system repeaters. There is nearly 700 km of fiber optic cable (5 cable types from lightweight to double- armored), in 41 sections of 1 to 40 km length. There are also spare TTE, PFE, and repeater electronics at AT&T’s New Jersey warehouses. This can be an extraordinarily valuable resource for science. New lightweight SL cable costs about $10/m or $10K/km. Lightweight cable can be used to link remote sites kilometers from a central hub. The sections of armored cable are essential for both shore access and exposed basalt seafloor. Each of the repeaters may be a potential node for ocean observatories. The first three pans of cable (82 km) and three repeaters have already been transferred from AT&T to IOC from the retired GPT system.

The principal challenge presented in the donation of this spare cable and equipment is where to store it. Both University of Hawaii (at Sand Island) and Rutgers University have offered some storage space for the spares. Because the AT&T storage facilities were sold several years ago to Tyco Telecommunications, the spare pans (21 ft. diameter) of cable and repeaters are currently stored at Tyco facilities at Guam, Honolulu, Portland, and Baltimore. Commercial storage rates for the spare cable available for single systems reach $20-150K/yr, depending upon storage location and cable volume. As the Guam storage facility is planned to be closed by Tyco in September, shipping costs to move the GPT spares now owned by IOC to Honolulu is being coordinated with the University of Hawaii Project Aloha. Negotiations with Tyco are currently underway in consultation with NSF to arrange for the
storage of these spares at rates substantially below commercial storage rates. If funds are not available for storage, then the donation of much of the spare cable will have to be declined.

Acquisition Timeline. The approximate timeline for action in acquiring these Cable Systems for science is noted in Table 4. Upon retirement, there is about six-month period to clear all matters before the books are closed. During this time the disposition of all cable station equipment, surplus cables and spare are concluded. Transfer of spare cable and repeaters must be arranged early. As there is no immediate need for space in the relevant cable stations, the actual transfer and licensing agreement can take place in six months or longer following the conclusion of an Agreement-in-Principle.

Because the European coastal portion of the TAT cables will be recovered and disposed (assuming no scientific reuse by the European science community), the final disposition of these systems will await retirement of TAT-9, when a cable ship will be hired to dispose of all systems at the same time.

IRIS is endeavoring to extend the timeframe for acquiring the Cable Systems in order to keep options open for the scientific community and NSF. However, commercial interests of the telecommunications companies will dictate the schedule.

### Table 4.

<table>
<thead>
<tr>
<th>Cable</th>
<th>Retirement Date</th>
<th>Decision on Spares</th>
<th>Transfer Agreement-in-Principle</th>
</tr>
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<tbody>
<tr>
<td>TAT-8</td>
<td>May 2002</td>
<td>Spares lost</td>
<td>November 2003 <em>Station Equipment temporarily saved at IOC request 11/2002</em></td>
</tr>
<tr>
<td>GPT</td>
<td>April 10, 2003</td>
<td>June 1, 2003</td>
<td>October 1, 2003</td>
</tr>
<tr>
<td>TAT-10</td>
<td>June 30, 2003</td>
<td>August 31, 2003</td>
<td>December 31, 2003</td>
</tr>
<tr>
<td>HAW-4</td>
<td>September 30, 2003</td>
<td>December 31, 2003</td>
<td>March 31, 2004</td>
</tr>
<tr>
<td>TPC-3</td>
<td>September 30, 2003</td>
<td>December 31, 2003</td>
<td>March 31, 2004</td>
</tr>
<tr>
<td>TAT-9</td>
<td>December 2003</td>
<td>February 2004</td>
<td>June 2004</td>
</tr>
</tbody>
</table>

Cable System Summary. The status of negotiations and discussions for these 3 Pacific and 4 Atlantic Cable Systems under discussion are briefly summarized. AT&T has submitted draft Transfer and License Agreements for consideration.

**Pacific Cables**

The Cable Owners have agreed in principle to transfer the cables for science, subject to an acceptable Transfer Agreement. There has been no fishing/trawling cable damage to any of these systems. IOC currently holds an AT&T license for space in the Guam Tanguisson Cable Station for TPC-1 and the Oahu Makaha Cable Station for Hawaii-2. These Cable Stations also serve GPT, TPC-3, and HAW-4. The University of Hawaii, which currently stores a pan of Hawaii-2 cable at its Sand Island facility, has expressed interest in helping with cable storage and is approaching Tyco regarding their local storage depot.

**GPT.** The entire system has AT&T repeaters. The American scientific interest in GPT is from Guam to the branch unit at about 2400 km west. IOC has signed a Transfer Agreement for 3 pans of surplus fiber cable (82 km) and 3 repeaters.

**TPC-3.** The US interest is the section west of Oahu to the Branch that uses AT&T repeaters. The Japanese scientific community is considering the western portion of the system. Significant spare cables and repeaters are located in Honolulu and Yokohama.

**HAW-4.** The entire system has AT&T repeaters. NSF has a funded proposal, Aloha Observatory, with an interest in using this Cable System. Significant spare cables and repeaters are located in Honolulu and Portland.
Atlantic Cables
Although AT&T has agreed in principle to transfer the cables for science, subject to an acceptable Transfer Agreement, the European Owners have expressed reservations in transferring the cable systems to a not-for-profit scientific organization such as IOC due to liability concerns. Rutgers University, which operates the LEO-15 cable near the AT&T Tuckerton Cable Station has expressed an interest in the Atlantic Cables. Rutgers has offered to help coordinate with the Atlantic Cable Stations and provide some storage space for spare cable system equipment. The European terminations of all of the Atlantic Cable Systems have had significant trawling/fishing problems and possess environmental requirements to remove cable from their coastal waters after use.

TAT-8. The system has AT&T repeaters from the US to the branch, and reaches the Mid-Atlantic Ridge. There have been two fishing/trawling problems beyond the first repeater at about 50 km out. If only the short coastal section of TAT-8 were used, the standard Cable Station Terminal equipment may not be needed (with perhaps significant savings of space and concomitant License space cost). There is license space available in the Tuckerton Cable Station.

TAT-9. The system has AT&T repeaters from the US to near the Mid-Atlantic Ridge. There is a record of fishing/trawling problems on the Canadian coast. Only the section of the TAT-9 system from the US Cable Station to the first branch and then to the Mid-Atlantic Ridge is being considered for scientific use by the US. The Manahawkin Cable Station in New Jersey may be closed after TAT-9 and TAT-11 retirement. Rutgers is exploring the possible re-use of the building, which could make possible the re-use of TAT-9. Significant spare cables and repeaters are located in Baltimore.

TAT-10. This Trans-Atlantic Cable could be used for a Mid-Atlantic Ridge observatory. The entire system has AT&T repeaters. There is a record of fishing/trawling problems from the European coast to northwest of Ireland, but none on the US side. Only the section of the TAT-10 system from the US coast into deep water beyond the Mid-Atlantic Ridge is being considered for scientific use by the US. There is license space available in the Green Hill, Rhode Island, Cable Station. However, there is a question whether this station may remain open in the future when TAT-12 and TAT-13 retire. Significant spare cables and repeaters are located in Baltimore.

TAT-11. The system has AT&T repeaters from the US to the section southeast of Newfoundland. There has been no record of fishing/trawling problems on the US side. The Manahawkin Cable Station in New Jersey may be closed after TAT-9 and TAT-11 retirement. Rutgers is exploring the possible re-use of the building, which could make possible the re-use of TAT-11. Significant spare cables and repeaters are located in Baltimore.

Future Implementation for Science. This section looks beyond the acquisition of the Cable Systems toward using the Systems for science. Many of these concepts have been outlined and discussed in the various reports referenced in Scientific Opportunities, and are mentioned here to provide context for these fiber optic Systems.

Scientific re-use of a fiber optic cable system changes its original use from a telephone system between two coasts to a system to provide telecommunications and power to the seafloor. There are a number of ways in which the systems may be modified, depending upon the complexity of re-use. Detailed discussions have taken place with the AT&T/Tyco engineers who designed these Cable Systems and have been offering their assistance in the Cable re-use effort. These people, led by Mr. Mark Tremblay, bring both key expertise and extensive good-will contacts throughout the AT&T and Tyco organizations. A group of 30 cable system engineers have been canvassed and have expressed interest in helping with engineering work in using the Cable Systems for science. Scientific re-use of these first generation systems is both technologically feasible and may be straightforward. Re-engineered spare repeaters or other in-line nodes may used for an observatory system, and the kilometers of spare cable being offered by AT&T may be used as branches off the trunk to remote instrumentation.

Two models have been followed in re-using coaxial submarine telephone cable systems. For TPC-1, an instrumentation package was spliced into the cable, which remained connected to the cable stations on either end. For Hawaii-2, the original cable was cut in the middle and the Hawaii-2 Observatory (H2O) junction box was attached to the section going to the Hawaii terminus. This approach permits easy repair, replacement, and additions of sensors. The other section of the Hawaii-2 cable is effectively retired on the seafloor, unused. Furthermore, since

Additional information may be found at www.iris.iris.edu/cable/info.htm
the repeaters on the unused section of cable are not powered, this power is available for scientific sensors. For Hawaii-2 this amounts to about 400 watts. Both of these models used space in the AT&T cable station for the terminal equipment. The sections of cable near the cable stations, which were originally buried by AT&T, were left undisturbed.

The Hawaii-2 re-use model may be applied for the fiber optic systems. Cutting a cable system in the middle will yield about 4-9 kW power on the seafloor. Using loopback telemetry, the system bandwidth may be used from either cable station. In this model a junction box installed at one end becomes a server to other junction boxes in a star topology (spokes from the center). These remote boxes would be connected by electro-optical cable to the server. Sensors would be added and modified at the junction boxes in the manner of the Hawaii-2 Observatory. The cable system is powered from the Cable Station, and the basic telemetry would be modified to carry IP traffic. With the large amount of available power on the seafloor, the junction boxes can also serve at docking stations for Autonomous Underwater Vehicles (AUVs), which can get power and upload/download data after service runs to remote instrumentation or other autonomous scientific surveys.

Following the example from TPC-1, nodes may be spliced into multiple points along the cable. This requires cutting, lifting, and splicing into the system. An installed node may serve both local instrumentation and additional junction boxes connected by cable. There are margins built into the repeaters for maintaining signal characteristics. One must be careful in splicing additional cable or sensors that these margins are strictly adhered to. The earlier SL280-series cable systems have closer repeater spacing, and effectively greater margins. Splicing into the middle of a cable system is inherently risky. However, if one designs to minimize risk to the whole system, then one can potentially install many scientific nodes along the re-used cable system. Installation of such nodes will require a cable ship with splicing equipment.

H2O re-used the RF spectrum available in the coaxial cable, subdividing the bandwidth into channels connected to standard modems. Care was taken to maintain the frequency and power standards that the repeaters were designed for. Similar care is required for the fiber systems. The electro-optical repeaters operate at 1.6 Amps and communicate only at SL280 or SL50 data rates. Although the systems carry PDH traffic, appropriate terminal modifications, complimented with corresponding node hardware, can enable the system to carry Ethernet traffic and still permit control of the repeaters when necessary. Test circuitry built into the TTE and repeater loopback capabilities permit system testing on land within the Cable Station. The Seafloor Observatory nodes would then distribute the signal via IP protocols. Using standard IP hardware minimizes development for the seafloor system mirrored at the TTE in the Cable Station, while utilizing the highly reliable SL280/560 regenerators. There is a wealth of available talent in the former AT&T/Tyco engineers who designed and built these Cable Systems, many of whom are actively interested (and some already actively participating) in helping use these Cable Systems for science. A recommended approach is to fund a workshop inviting broad participation to recommend a design concept.

The Hawaii-2 system was used in place. One of the major new ideas for re-using these retired fiber optic systems is to re-locate them. One possibility, extending the prior example, is to cut the cable, then recover and re-lay the section at the end of one or both of the two pieces. One end of the cable remains connected to the cable station. For example, the Hawaii-4

![Possible ideas for re-locating Pacific cables.](image.png)
Cable can be divided, using one section off the coast of the US (as illustrated in Figure 5, or perhaps southward off of the California coast) and the other end northwest or south of the current Hawaii-2 Observatory. GPT could be relocated to the region of the TAO/TRITON array of El Niño buoys in the tropical Pacific Ocean (shown in Figure 5) or perhaps along the Marianas-Bonin active margin. TPC-3 could be wrapped around the Hawaiian Islands. One can move as much cable as available up to the point where the cable is overlain by a newer cable system. To get more, the only recourse is to recover individual sections, leaving the overlying cable undisturbed, and then splice sections together. There are hundreds to thousands of km of cable that can be re-located without disturbing overlying cable. However, in moving cable systems, close coordination with other cable owners may be necessary, if one plans to go across their cable on the seafloor.

Extending this model further, one can potentially pick up thousands of km of cable and re-lay it entirely in a new location. For instance, New Zealand has already expressed interest to NSF in collaborating on moving a section of TPC-3 to the South Pacific, connecting a ridge observatory on the Pacific-Antarctic Ridge to Christchurch on the South Island, NZ. The longest open section on TPC-3 is about 5,000 km near Oahu to the branch point. There are many such opportunities that can be conceived. In this model, one must provide for a cable station, arrange for permitting to cross the beach, and bury the cable in the shallow coastal region. To do this would require splicing recovered fiber sections with armored cable (available as AT&T spares) at the coast. To develop this project, close collaboration is necessary with the country where the cable station would be provided.

Available AT&T spare cable can be used outright without the necessity of picking it up from the seafloor. These sections can be used as coastal segments or spokes from seafloor nodes. For example, the Bermuda Atlantic Time-series Study (BATS) at Hydrostation “S” just 15 nautical miles from Bermuda has been monitored since 1954. There is available spare cable in the Baltimore depot that could be used to link this site to Bermuda; and since the length is relatively short, no repeater would be required.

AT&T and Tyco have indicated it is very feasible to pick up and re-lay fiber cable. However, it would be very difficult to re-locate buried sections of cable. Hence, this section focuses on unburied sections of cable. A cable ship can easily pick up a thousand km of cable, and a larger ship can pick up 3-4,000 km of cable. At the height of the telecommunications boom when cable ships were at a premium and busy laying cable, the going rate was about $100K/day. The current rate for a cable ship is now about $20K/day. Under average conditions, cable can be recovered at 1-1.5 knots, and best-case conditions at 3 knots (worst case can be as slow as 0.1 knots) Hence under average conditions, 1,000 km of cable can be recovered at about $900K for a $40K/day cable ship. It can be re-layed at about 5-6 knots, for about $180K. Thus the cable relocation cost, not including transit, for the average case is about $1.1M per 1,000 km. This cable cost may be compared to the cost of new fiber optic cable on a reel in a warehouse at about $10/m, or $10M for 1,000 km—this new cable cost does not take into account the additional cost of the required repeaters. These costs do not include transit costs to bring the ship to the site, or to move the cable to a new site. Assuming a speed of 12 knots, the cable ship transit cost is about $75K per 1,000 km. There would also be additional costs for site surveys, time on site for splicing, etc., but this provides an illustration for re-laying cable.

Conclusion. The successful scientific use of retired telephone cables for seafloor observatories has been demonstrated for TPC-1 (Kasahara et al. 1998) and Hawaii-2 (Butler et al., 2000), where the Hawaii-2 Observatory (H2O) between Hawaii and California on the seafloor at 5,000 m depth has provided over 99% data availability for the Global Seismographic Network since October 1999. The coaxial SD Systems have provided both dependable power and telemetry. The scientific potential has spawned new NSF-funded geomagnetic and biological instrumentation for the H2O site, and an ODP borehole. The newly retiring, first-generation fiber-optic cables systems offer 10 times more power, and nearly 1000 times more telemetry bandwidth than the coaxial systems, TPC-1 and Hawaii-2. The new opportunities that these fiber-optic cable systems now present for science are limited only by our imagination.

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Additional information may be found at www.iris.iris.edu/cable/info.htm
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