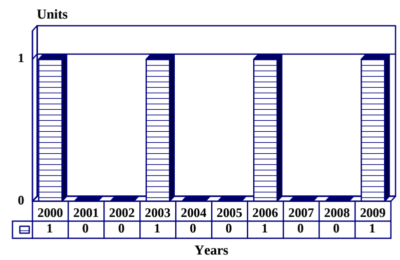
French Nuclear Propulsion - Archived 5/2001

Outlook

- No sister ship expected for the *Charles de Gaulle* carrier
- Same reactor will be on upcoming Barracuda class SSNs as well
- Cooperation, technology transfer to other submarine programs unlikely (India, Brazil)
- Successor model of reactor not expected until Barracudas done

10 Year Unit Production Forecast
2000 - 2009



Orientation

Description. Pressurized water nuclear reactors used for shipboard propulsion and power-generation systems.

Sponsor
Délegation Générale pour l'Armament (DGA)
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Licensee. No production licenses have been granted.

Status. Production and service.

Total Produced. About 15 French-designed reactors of varying types are estimated to have been built.

Application. The reactors are designed for the production of steam, which in turn is used to generate propulsion power and electricity and to operate the soft-water plant onboard. On the aircraft carrier, the steam is also used for driving the ship's catapult installations.

The use of nuclear fuel allows virtually unlimited operating endurance at low noise levels.

Platform. The CAS-48 reactor was used on the Rubis/Améthyste and L'Inflexible class SSNs. The K-15 is on the Le Triomphant class SSBNs, while two of these reactors are used to power the *Charles de Gaulle* aircraft carrier.

The new Barracuda class SSNs will also use the K-15 nuclear reactor.

Price Range. Estimated to be roughly between US$100 and US$250 million.

Technical Data

Specifications

Power Output CAS-48:	48 MW
Power Output K-15:	150 MW

Design Features. If the S5W-derived reactors used in the first French ballistic missile submarines are excluded, all French nuclear propulsion systems are based on the CAS-48 reactor originally designed for the Rubis class submarines. The severe constraints under which this system was designed have resulted in a power train that is noisy, inefficient and expensive to maintain. A Canadian technical evaluation of the system was highly critical of safety aspects of this design.

The Rubis class were extensively rebuilt, alleviating the problems experienced and improving the power train. The basic problem, the extremely small hull of this type of submarine, remains insoluble. A recent series of accidents with this class (in all fairness, few of which were power-related) has highlighted these shortcomings and may have been a factor in the initiation of the new-generation French SSN.

The Le Triomphant class ballistic missile submarines and the *Charles de Gaulle* aircraft carrier do not suffer from this cramped hull, and the opportunity has been taken to redesign the reactor to increase power output and safety considerations. The future French attack submarines can be expected to use a larger hull in order to accommodate the improved system.

The CAS-48 reactor is a single-pass natural circulation system using a single steam cooling loop. No provision for backup or fail-safe operation is made in the event of mechanical failure. The reactor uses nuclear fuel with a very low level of enrichment. No provision is made for rafting elements of the machinery. A modified version of this system with facilities for rafting some main components is used on the Améthyste class.

Operational Characteristics. As a matter of national policy, purchase of highly enriched uranium from abroad is discouraged. Consequently, the slightly enriched fuel used in the French reactors means that the time between refuelings is very short. Typically, a Rubis class submarine needs to be refueled every three to five years, as opposed to every 10 years for a US Los Angeles or British Trafalgar class boat. The K-15 reactor on the *Charles de Gaulle* aircraft carrier is of improved design and reportedly has the capacity to provide five years of continuous operation at 25 knots before refueling.

All French nuclear reactors and reactor cores are manufactured by the French industry (DCN Indret and Technicatome for the *Charles de Gaulle* carrier).

Variants/Upgrades

CAS-48. This is the reactor system designed for the Rubis and Améthyste class submarines described under **Design Features**.

K-15. An enlarged version of the CAS-48 with triple coolant pass rather than single pass, multiple rather than single steam loops and using more highly enriched fuel. This is the powerplant of choice on the newer Le Triomphant class SSBNs, and on the carrier *Charles de Gaulle*.

A slightly modified version will be used on the upcoming Barracuda class attack submarine.

Program Review

Background. France began conducting an independent nuclear propulsion research program in 1958. The keel for the submarine FS *Gymnote* was laid in 1958 as a nuclear attack submarine. But in 1959, the high cost of its nuclear program forced the French Navy to change the *Gymnote* to a diesel-electric powerplant. Research of nuclear propulsion continued at a low level.

In 1963, France made the decision to base its strategic nuclear deterrent on submarines. Consequently, nuclear reactor research was reinstated as a high-priority effort. In contrast to the British program, the French went straight to ballistic missile submarine construction, without first constructing a fleet of attack submarines. At that time, the construction of only five nuclear-powered submarines was envisaged, and the development of an indigenous nuclear reactor design was not regarded as cost-effective. As a result, the US-designed S5W reactor was used for these boats. The reactor for these submarines was reportedly derived from US commercial nuclear reactor technology – which came from submarine research in the first place.

The first French nuclear-powered submarine, FS *Le Redoutable*, conducted sea trials in 1971 and was commissioned in December 1971. But tactical experience soon indicated that the concept of using diesel-electric submarines to escort nuclear-powered ballistic missile boats in and out of port was not viable. The French Navy therefore formulated a requirement for nuclear-powered attack submarines for that particular mission.

At this time, the French DCN design bureau had envisaged an export market for nuclear-powered submarines. Such submarines would have to be inexpensive in order to fit likely procurement budgets. This implied using a small hull and a limited ASuW-oriented sensor suite derived from the original Agosta class. Thus was born the export-oriented design later known as the Rubis class. They are the smallest fully operational nuclear-powered submarines (not including research submarines) in service with any Western navy.

A small reactor for the Rubis class submarines, designated the CAS-48, went into development in the early 1970s. The confined dimensions of the submarine pressure hull placed enormous demands on the reactor designers. The requirements of the anti-nuclear proliferation treaties dictated the use of nuclear fuel with low levels of enrichment (a product called Caramel). This, however, meant lower power density, a factor which the French designers hoped to offset by adopting liquid metal cooling for these reactors. A study of the problems involved quickly turned the attention to the pressurized, water-cooled reactors.

Space constraints prevented the installation of more than a single steam coolant loop, while the reactor was restricted to a single primary coolant pass (as opposed to a triple pass on the American S5W). It was necessary to adopt natural circulation, not in order to reduce noise levels, but because hull space was insufficient for the pumps and piping needed for forced circulation. All these factors further depressed the power density of the reactor, limiting the output and thus the speed of the submarine. Finally, confined hull dimensions prevented main machinery rafting. A turbo-electric main drive system was used in an attempt to reduce noise emissions, further reducing usable power output.

Although the design was not well suited to its requirements, the French Navy did acquire the Rubis class, perhaps in the hope of enhancing its export profile. A derivative of the same basic design, featuring a limited degree of main machinery silencing, was undertaken later in an attempt to produce a version with better anti-submarine warfare (ASW) capabilities. As a result of those changes, units five and six of this batch became known as the Améthyste class.

The same design was also offered to the Canadian Navy to satisfy a requirement for up to 12 nuclear-powered submarines for patrolling Arctic waters. The competition for this project came from the British Trafalgar class. However, a Canadian investigation of the Rubis design found it to be unsuited to their requirements. Further, as a result of the investigation, reservations were expressed about the safety of the entire nuclear propulsion system, with particular reference to the single steam loop and the cramped reactor compartment.

In the late 1970s, development began on a new reactor type intended for new ballistic missile submarines. The reactor, later known as K-15, was fundamentally very similar to the CAS-48 in the Rubis class but took advantage of the more generous proportions of the hull to allow rafting of the main machinery; provide additional steam cooling loops; and increase the number of passes made by the primary reactor cooling fluid to three. A much higher level of fuel enrichment was also adopted for these reactors. The result was a substantial improvement in power density, noise profile and operational safety.

In 1982, DCN Indret and Technicatome began designing the propulsion system for the new aircraft carrier *Charles de Gaulle*. This aircraft carrier uses two K-15 reactors. The French Navy received FFr100 million in the 1982 budget to build a prototype reactor at Cadarache. The Le Triomphant class uses one of these PW reactors on each submarine, with an output of 150 MW. The lead boat, the *Le Triomphant*, was launched in July 1993. The *Charles de Gaulle* uses two reactors, but because of if its substantially larger mass is not able to achieve a top speed higher than about 27 knots, while its predecessor Clemenceau class achieved 32 knots. The 61 MW turbines are from GEC Alsthom.

In 1992, the French Navy radically cut back its shipbuilding plans. The second Le Triomphant class submarine was suspended, while the remaining vessels of the class were canceled. The two remaining Améthyste class submarines were also canceled. However, the French Ministry of Defense (MoD) said at the time that a second Charles de Gaulle class aircraft carrier would be built, with construction to begin in 1997.

Also during 1992, negotiations were initiated between France and Taiwan for the purchase of Rubis class submarines from France. These negotiations did not lead to any concrete sales, though, since Taiwan does not have the infrastructure in place for the operation of nuclear-powered submarines.

In 1992, detailed photographs of the Chinese Xia class ballistic missile submarine became available. These showed the class to have a very strong design resemblance to the French Le Redoubtable class ballistic missile boats. The only major change was a reduction from 16 missiles to 12 due to the larger dimensions of the Chinese missile. The sensors installed were largely French. Consequently, it is highly probable that the reactor also follows the French practice – suggesting that the US S5W technology has spread to China as well. This, incidentally, also raises the question of the reactor installed on the Han class attack submarines.

In late 1993, the French government released The White Book, a public statement of French defense policy. This re-affirmed the long-range strategic plan for the construction of four new ballistic missile submarines to replace the six original boats of this type. Two of these are under construction, one having been suspended around 1993. These plans suggested that the remaining two Le Triomphant class boats be canceled and replaced by a new design. This plan was later turned around again, however, and the third and fourth Le Triomphant class subs were reinstated.

The French Navy also initiated a design program for a new-generation nuclear-powered attack submarine. Preliminary design studies, originally planned for 1997, were brought forward to late 1994 due to a work shortage at the Cherbourg shipyard. Full-scale development of the new submarine was scheduled to begin in 1997, and probably did. This estimation is based on the information activity around that time concerning the future plans of the French submarine fleet. No specific announcement on the issue has been released.

In 1995, it was stated that the land-based prototype of the K-15 reactors for the *Charles de Gaulle* had developed serious cracks in the support structure, presumably necessitating remedial work that added 4,000 tons of steelwork to the ship, partly in the form of additional reactor shielding.

In October 1997, the *Charles de Gaulle* was formally declared a nuclear installation, and a temporary plant was used to raise steam for the operation of catapults for trials in August and October. The two reactors went critical for the first time on May 25 and June 10, 1998, respectively. Sea trials were scheduled to begin by mid-1998 and last through May 1999. However, delays affecting safety critical software and nuclear certification postponed the beginning of sea trials to November. Due to the rescheduling of the sea trials, commissioning was not expected before late 1999. No information has been obtained, however, that this has indeed taken place. It is more likely that the ship will not be fully operational until in the summer or fall of 2000.

In the sea trials, the ship suffered a fire in its engine compartment and had to return to port several days short of its planned week-long engagement. The problems in the propulsion system reportedly involved "an electric motor linked to the main engines," according to a spokesman for DCN.

Funding

This program is funded by the French MoD.

Recent Contracts

No information has been made available to the public.

Timetable

Year	Major Development
1958	France begins nuclear reactor development
1959	French Navy cancels plans for nuclear attack submarine
1963	Navy revives nuclear submarine plans
1971	Navy commissions first nuclear submarine
1970s	Navy develops improved reactor (K-15)
1985	Navy begins plans for a new reactor
1998	The two K-15 reactors on the *Charles de Gaulle* go critical
2008	The first of Barracuda class submarines expected to be launched
2017-2018	New reactor model expected to become available
2020	Sixth Barracuda to launch

Worldwide Distribution

France (Due to the proprietary nature of the program, this reactor is used on French ships only.)

Forecast Rationale

Considering the problems experienced with the aircraft carrier *Charles de Gaulle*, a second copy of this ship is unlikely. Even though many of the issues involved are unrelated to the nuclear reactor and some are a direct result of the program taking so long to finish, it is not realistic to expect that an approval for a second ship of this type would be obtainable either among the political decision-makers or from the general public.

Presently the next application for the K-15 reactor is the upcoming Barracuda class submarine. The first reactor may in fact have already been delivered to the builder, or could be delivered momentarily, since the first boat is expected to be launched around 2008 (for starting of the sea trials). The last ship is expected to be ready by 2020.

The reactor for this platform has been said to be the same basic K-15 design as on today's Le Triomphant class SSBNs, likely with minor improvements.

France will not export nuclear-powered submarines in the foreseeable future, due to the proprietary nature of the technology. It remains to be seen to what extent France will cooperate in the development of nuclear power train systems with other countries. India, for one, is still in the process of developing an indigenous nuclear submarine, but it is increasingly warming up to the Russian shipbuilders on other programs at least. It is therefore less likely that any nuclear reactor technology would be transferred to that country – particularly concerning the extreme political sensitivities surrounding India, and its neighbor Pakistan, for the *faux pas* of carrying out nuclear explosion experiments two years ago.

The speculated teaming on aircraft carrier design with the British is a possibility but the UK part appears rather reluctant to any cooperation dealing with fundamental issues such as the propulsion system. Brazil is also known to still harbor nuclear aspirations for submarines, but it is unlikely that any close exchange of information would be established in the nuclear area there, either. For France, nuclear power appears to be a highly sensitive issue of national competence and a statement of sovereignty.

Any design of a new nuclear reactor (a successor to the K-15) is expected only after the Barracuda series has been completed. The availability dates below are driven by the Barracuda construction schedule.

Ten-Year Outlook

ESTIMATED CALENDAR YEAR PRODUCTION

			High Confidence Level			Good Confidence Level			Speculative				
Designation	**Application**	**Thru 99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**Total 00-09**
FRENCH NUCLEAR PROPULSION	SSN/SSBN (FRENCH NAVY)	13	1	0	0	1	0	0	1	0	0	1	4
FRENCH NUCLEAR PROPULSION	Prior Prod'n:	2	0	0	0	0	0	0	0	0	0	0	0
Total Production		15	1	0	0	1	0	0	1	0	0	1	4